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SEISMIC SAFETY

Mission Bay San Francisco

September 1986

San Francisco Department of City Planning

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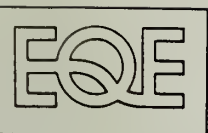


San Francisco Department of City Planning

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SEISMIC SAFETY SPECIAL STUDY FOR MISSION BAY

September 1986

Prepared for:

CITY AND COUNTY OF SAN FRANCISCO

**Department of City Planning
450 McAllister Street
San Francisco, California 94102**

EQE Job Number: 86072.01



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SEISMIC SAFETY

Introduction and Summary

This summary of seismic safety considerations is one of about 20 special studies for Mission Bay. The summary presents an overview of a preliminary earthquake risk assessment of the Mission Bay Plan, which was performed by EQE Incorporated (EQE). The purpose of the study is to develop a preliminary assessment of potential seismic hazards at the site and make recommendations for reducing the risks posed by the hazards to the Mission Bay Project.

This assessment is based on:

- visual inspection of the Mission Bay site
- review of generally available information such as the site geology and seismology
- review of summary soils reports prepared by Dames & Moore
- brief review of available structural drawings, criteria, architectural renditions
- engineering judgment and experience

Extensive use was made of EQE's background and knowledge of the performance of soils, structures, foundations, and transportation and utility systems during past destructive earthquakes in developing recommendations to minimize the earthquake risk to the site.

The results present general seismic risk assessments. Detailed engineering studies were not performed. The assessment is intended to identify on a preliminary basis possible problem areas. Detailed engineering reviews may substantially alter the preliminary conclusions once design concepts are finalized.

Major findings and recommendations are summarized by subject area. The subjects summarized include the following:

- Seismic Hazard to Mission Bay Site
- Risks from Seismically Induced Soil Failure
- Risks to Buildings
- Risks to Lifeline (Utility and Transportation) Systems
- Earthquake Preparedness Planning

Seismic Hazard to the Mission Bay Site. The seismic hazard to the Mission Bay site is high due to the close proximity of the San Andreas, Hayward, and Calaveras fault systems, which are from 8 to 20 miles from the site. For the Maximum Credible Earthquake, maximum ground shaking with a Modified Mercalli Intensity of IX (out of a maximum intensity rating of XII - see Table 3-1) is expected due to a Magnitude 8.3 event (which is comparable to the 1906 San Francisco earthquake) centered on the San Francisco Peninsula segment of the San Andreas fault. For the Maximum Probable Earthquake, maximum ground shaking with a Modified Mercalli Intensity of VIII occurs due to a Magnitude 7.0 event on the San Andreas fault. Poorly engineered facilities will suffer significant damage due to these high levels of ground shaking. Well engineered facilities are expected to perform well and to sustain moderate but repairable damage.

These high intensities are also due to the nature of the soils at the site. The site soils consist primarily of random fill material which is underlain by 30 to 100 feet of natural bay mud. Soft soils such as these typically show higher amplification of ground motion than that which would be experienced at a rock or stiff soil site.

The hazards and the resulting risks to the Mission Bay site are typical for several large areas of San Francisco. For example, similar hazards exist for most of the northeastern and eastern shoreline areas of San Francisco, including the Marina, Fisherman's Wharf, the Financial District bounded by Telegraph Hill, the Bay Bridge approaches, and The Embarcadero and Montgomery Streets, much of the area south of Mission Street extending to Hunters Point, and San Francisco International Airport.

Risks from Seismically Induced Soil Failures. Several types of seismically induced ground failure have been identified as key concerns at the Mission Bay site. These include soil liquefaction, settlement, and lateral spreading. Liquefaction occurred here during the 1906 earthquake and will likely occur during future large magnitude earthquakes. These types of soil failures can cause severe damage to buildings with inappropriate foundations. However, seismically induced soil failures can also be tolerated by properly designed foundations, as illustrated by the performance of such foundations in many past earthquakes.

Pile foundations are currently envisioned for many of the buildings at the site. This type of foundation provides excellent protection against liquefaction and is strongly recommended to mitigate damage from this hazard. The Ferry Building survived the 1906 earthquake because it was built on such foundations (current design methods call for much more sophisticated and earthquake resistant details than were used in the Ferry Building). Other types of foundations may also be appropriate, depending on the building type, configuration, function, and occupancy.

One to two feet of soil settlement (and locally more) may occur due to soil consolidation under strong ground shaking. Soil will settle away from properly designed pile supported buildings and bridges, leaving the structures in their original positions. Underground utilities will tend to move downward with the soil and may be damaged at their connections to pile supported buildings. Consideration should be given to providing flexibility at the utility-to-building connection to minimize potential damage. Nevertheless, damage to the streets and to underground utilities will be much greater than at other parts of San Francisco with better soils or rock. Typically, badly affected streets will remain passable for light trucks and four-wheel drive vehicles. It is difficult and may not be cost-effective to attempt to stabilize such soils, except at more important locations, such as bridge approaches. To the best of our knowledge, no such stabilization has been attempted at any other location in San Francisco.

Lateral spreading or lurching (horizontal movement as in a landslide) of the soil may occur within 200 yards of the China Basin Channel. To minimize possible damage from this hazard, structural foundations located within this zone should

have additional special consideration given to the lateral loads that could be imposed by the soil as it flows towards the open ship channel. If some of the open space which has been proposed is converted to wetlands or a lagoon this will also increase the risk in the area. Special earth retaining provisions may be required.

Access to the old Third and Fourth Street bridges over the China Basin Channel will likely be severely impaired by a combination of soil settlement and lateral spreading. However, it is expected that alternate routes out of the Mission Bay area will be available underneath I-280 (see discussion on "Preparedness Planning" which follows) and temporary loss of access to these bridges should not be a significant problem.

We understand that a wick drainage system is currently under consideration for parts of the site. A decision on this will be made after that alternative is measured against other alternatives such as pile foundations. This would preconsolidate the site and reduce the need for pile foundations. If this system is implemented over large areas of the Mission Bay site, many of the concerns discussed above will need to be reassessed for their applicability to the new site conditions.

Risks to Buildings. The selection or development of appropriate seismic design criteria for buildings is one of the most important steps in the design or evaluation of a facility. The development of seismic criteria should include consideration of geology, seismology, seismicity, soils engineering, structural dynamics, structural design, earthquake engineering, and experience data from past earthquakes. The *Uniform Building Code* (UBC) and the *San Francisco Building Code* (SFBC) may not provide an acceptable level of protection for certain facilities. In many cases the UBC does not adequately address specific site locations, site conditions, building configuration, structural set-backs, redundancy, torsion, ductility, differences in stiffness, or adequate design detailing. For example, recent strong earthquakes have shown that UBC seismic requirements for sites on deep, soft soils subjected to strong, distant earthquakes may be inadequate.

Without actually having completed structural drawings of the proposed facilities to review, we can only make general comments on the factors which should be

considered during design. Areas which should be specifically addressed are the following:

- **Seismic criteria.** Response spectra for the site should be developed and the requirements of the UBC and/or the SFBC concerning soil amplification should be carefully reviewed.
- **Structural system.** Certain types of buildings tend to suffer more damage in strong earthquakes. Further, the engineering profession has limited experience with the performance of some building systems in strong motion earthquakes. Thus, the construction of certain types of buildings, such as taller concrete frame buildings without shear walls may be restricted. Connection details for tilt-up concrete buildings should also receive additional attention.
- **Peer review of design.** We have found that peer review is a very cost-effective way of reducing risk and improving the design of new buildings. This should be done throughout the design process from reviewing architectural renditions of buildings through checking detailed design calculations. Early involvement of an experienced earthquake engineer will help ensure that adequate consideration is given to factors that are not specified by building codes such as the building geometry and structural system used in the design. By considering how structures with similar design characteristics have performed during past strong motion earthquakes, undesirable configurations can be modified early in the design process. This will help ensure good performance during a major earthquake.
- **Construction quality assurance and control.** Inspection of the building during the construction stage ensures that all detailing is carried out adequately and that construction practices are of the highest quality.
- **Inspection by the design engineer during construction.** Continued involvement of the design engineer throughout the project ensures that construction conforms to the design drawings. In addition, the design

engineer can answer any questions or clear up any uncertainties on the part of the contractor.

As discussed earlier, the seismic hazards at Mission Bay are comparable to those at many other large areas of San Francisco. The buildings at Mission Bay, when completed, will represent the state-of-the-art in earthquake engineering, given the usual attention by the engineering staff of the city. If the above recommendations are followed, increased safety at a very moderate price will ensure that the buildings will represent low to moderate seismic risks. That will be in contrast to many other parts of San Francisco where risky older buildings predominate. Overall, the risks for injury from an earthquake to inhabitants of Mission Bay will be lower than most of San Francisco.

Risks to Lifeline Systems. Lifeline systems included in the Mission Bay project include the following components:

- Electrical power
- Communication
- Gas and liquid fuel
- Water and sewage

The primary risk to lifeline systems (excluding transportation) is due to settlement of site soils and rupturing of utility connections. Historically, underground utilities have experienced damage to connections between pipe sections due to uneven settlement of the ground surface. In addition, the utility interface with pile supported structures has also proven to be a problem area since utilities move downward with the soil and tend to fail at their connection to the unmoving structure. Considerations should be given to providing flexibility at the building-to-utility connection.

Extensive experience data on the performance of underground pipes exist. The experience points out clearly that certain types of pipe are more vulnerable to settlement. For example, for communications conduit, steel conduit perform much better than polyvinyl chloride conduit. Ductile iron and steel pipes perform much better than cast iron or concrete pipes for potable water and waste water applications. We recommend that the City of San Francisco carefully consider the

design of the underground facilities and retain consultants to ensure maximum application of current knowledge.

Preparedness Planning. Because of the somewhat isolated nature of the Mission Bay site, special consideration must be given to egress from and access to the site, both by residents of the area, those who are employed in the area, and emergency personnel. The potential problem areas which were investigated include the following:

- **Performance of the elevated highways which run along portions of the perimeter of the site.** If structures built within the Mission Bay comply with the recommendations made earlier, we expect minor to moderate damage. Nonetheless, if an earthquake occurs during working hours on a weekday, residents of the area who work elsewhere will be anxious to return home. At the same time, people working in the area will be anxious to return to their own homes. Consequently access to and egress from the area is important. One important factor will be the performance of elevated highways in the area. Will they collapse, making it impossible to get into or leave the area? It is very likely that the elevated highways will suffer considerable damage; however it is unlikely that general collapse will occur. The elevated highways themselves may not be passable, but this will not block access to and egress from the Mission Bay site. As long as there is more than one surface street going under the elevated highways, access to and egress from the area will not be a problem immediately following the earthquake. If a transportation plan is chosen which has only one major street with access under I-280, a detailed engineering analysis of the highway should be performed to quantify the risk to the highway. Surface streets will suffer damage, but will remain generally passable and probably be restricted to emergency vehicle access.
- **Performance of the Third Street Drawbridge.** This bridge is not expected to collapse, although some deformation of the structure may occur so that the bridge will not open to traffic. It is expected that some settlement of the soils abutting the bridge would occur. If the

drawbridge is down at the time of the earthquake (which is the most likely position), the bridge should be passable by emergency vehicles as soon as fill material is brought in to provide temporary approaches.

- **Performance of the Fourth Street Drawbridge.** This bridge has a high likelihood of being damaged during an earthquake and will probably not function properly. Again, it is unlikely that the drawbridge will be up during the event, so passage may be possible. It is expected that large deflections of the counterweight will occur, so it is possible that the counterweight will collapse and the road be blocked. There will be significant ground settlement at the approaches, and again, fill would have to be brought in to provide temporary access if the bridge is passable.
- **Performance of the Electrical System.** Damage to both distribution and transmission systems is to be expected and emergency generators should be provided at important facilities. Damage will be minimized through the anchoring of equipment.
- **Performance of the Communications System.** All vital telecommunication equipment should be braced and anchored before the event to minimize damage. Because most of the distribution lines consist of buried cables, damage should be expected.
- **Performance of Gas Pipelines, Water, and Sewage Systems.** Large ground displacements will result in damage to all of these systems. This damage can be lessened by providing flexible connections to buildings and other structures and by providing as much redundancy in the system as possible.

Implications for Mission Bay

In the previous section, key seismic concerns for the site were summarized along with recommended approaches to minimize the resulting earthquake risks. These approaches will need to be modified as appropriate as overall land use planning for Mission Bay is finalized. Specific recommendations to reduce the risk to the

Mission Bay site will depend to a large extent on the type of foundation systems, structural systems, and overall site layout used in the final design.

To ensure the Mission Bay site represents a low risk during a major earthquake, the following steps should be implemented:

1. Establish a formal policy for constructing an earthquake resistant development at the site. This would include reviewing the adequacy of proposed seismic criteria and establishing a quality assurance program including independent design review for new design and construction.
2. Provide for the continued involvement of a seismic consultant throughout the development and implementation of all major phases of the project to review the seismic adequacy and implications of proposed construction based on a complete parcel-specific evaluation of soil conditions. Ongoing involvement of this consultant throughout the review process will ensure designs have adequate consideration of seismic performance early in the review process and avoid expensive modifications late in the design.

Also provide for a review of the adequacy of central lifeline systems serving the Mission Bay area, and connections with individual buildings developed on the site, in terms of materials and construction methods to withstand extensive damage from a major seismic event and consistent with requirements for city building permits.

3. If a transportation plan is chosen which has only one major street with access under I-280, a detailed engineering analysis of the highway should be performed to quantify the risk to the highway. If there is more than one surface street going under the elevated highway, access to and egress from the area will not be a problem immediately following an earthquake.
4. It may be possible to regain access across the Third and Fourth Street drawbridges if earthquake preparedness planning includes the provision of fill material (perhaps as part of an earth berm within nearby open

space areas) to rebuild temporary bridge approaches to permit emergency access.



**PRELIMINARY EARTHQUAKE RISK
ASSESSMENT OF MISSION BAY PROJECT**

**BACKGROUND REPORT FOR MISSION BAY
SEISMIC SAFETY SPECIAL STUDY**

September 1986

Prepared for:

CITY AND COUNTY OF SAN FRANCISCO

Department of City Planning
450 McAllister Street
San Francisco, California 94102

EQE Job Number: 86072.01

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1. INTRODUCTION

Mission Bay presents a unique and challenging development and planning opportunity for the City of San Francisco. The nearly 300 acres of relatively undeveloped land at Mission Bay can be developed into a living and working environment unlike no other in San Francisco.

The planning process associated with Mission Bay has been comprehensive. One part of that planning process has been an analysis of just what the seismic hazard to Mission Bay is.

Today we have a good understanding of earthquakes, their effects, and potential dangers. We also have the technical knowledge, planning skills, and experience to design building systems to be highly earthquake resistant.

During the past few years, the seismic requirements of building codes have changed dramatically, reflecting our increasing knowledge and awareness of the hazards. The earthquake risk to many existing facilities is unnecessarily high because they were built without adequate earthquake resistant features and with no earthquake hazard abatement planning. The problems facing the decision-maker are how to identify the risks, set objectives, and make the appropriate decisions. The purpose of this preliminary earthquake risk assessment is to provide the information needed to help in that decision-making process.

1.1 Site Description

The Mission Bay Project area is a relatively undeveloped area at this time. The location of the project is shown in Figure 1-1. The perimeter of the project can be described as Townsend Street, China Basin Street, Mariposa Street, and Seventh Street (see Figure 1-2).



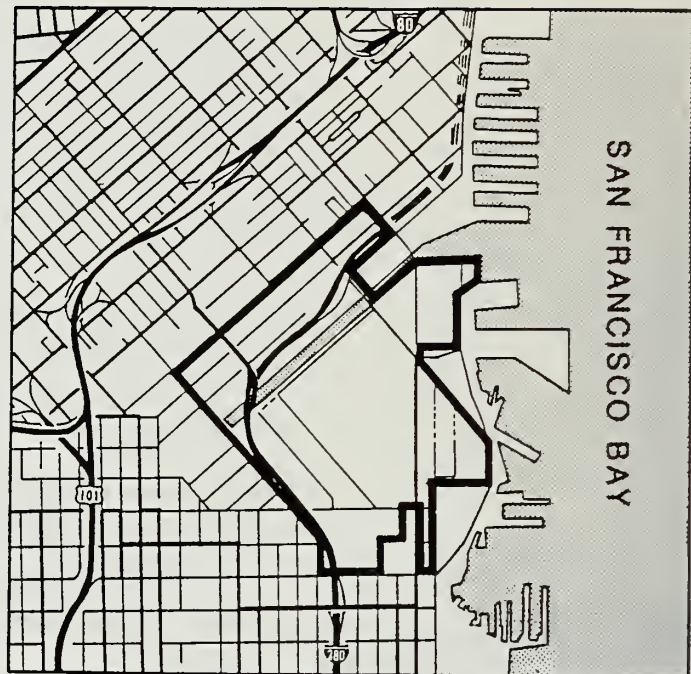


Figure 1-1: Location of the Mission Bay Project Site

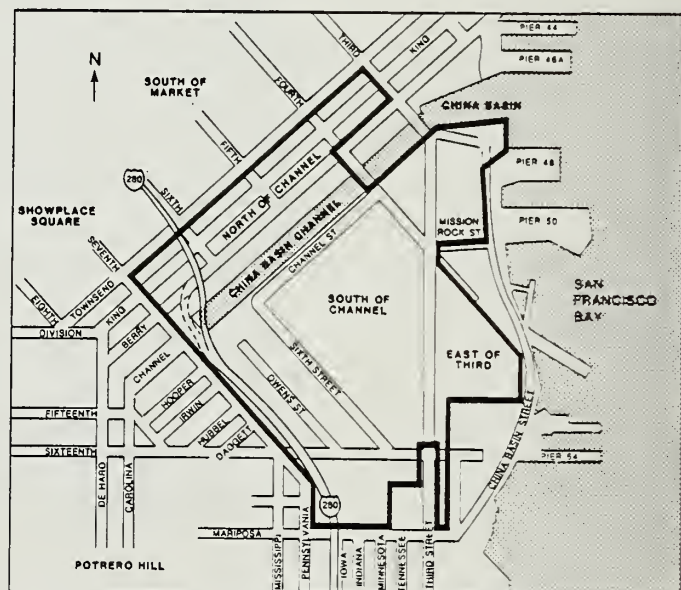


Figure 1-2: Site Plan of the Mission Bay Project

Virtually all private land is held by Santa Fe Pacific Realty Corp. This means full development of the project has a very high probability. None of the existing structures at full build-out will remain except for the old firehouse located at 1300 Fourth Street and the houseboats on China Basin Channel. Various design concepts for the area are discussed in *Choices for Mission Bay: Planning Considerations* (Reference 1) and are discussed in Chapter 4.

1.2 Scope of Work

In order to provide a preliminary earthquake risk assessment, EQE performed the following tasks:



1. Tour of the project site for the purpose of familiarizing EQE with the general layout of the project and to identify potential risks and hazards, including topographic and infrastructure features. Particular attention was paid to features which might impact on access to or egress from the site in the event of an earthquake.
2. Brief review of the available engineering data (for bridges and highways) in order to determine the general nature of the designs and their primary structural characteristics.
3. Review of soils reports and available drawings, criteria and architectural renditions.
4. Review of freeways and bridges.
5. Preparation of a report summarizing our findings and recommendations, when appropriate.

1.3 Report Outline

A summary of the findings and recommendations is presented in Chapter 2. Chapter 3 presents a brief discussion of the seismic hazards at the site. Chapter 4 discusses various building types within the project, the development of seismic criteria and codes, and historical performance of buildings in previous earthquakes. Chapter 5 discusses various lifeline systems at the site, their design criteria, previous performance and expected performance. References are listed in Chapter 6. Appendix A provides background information on the seismic hazard in the San Francisco Bay Area.



2. SUMMARY AND RECOMMENDATIONS

SUMMARY AND RECOMMENDATIONS

2.1 Summary

The purpose of this study is to develop a preliminary assessment of potential seismic hazards at the site and make recommendations for reducing the risks posed by the hazards to the Mission Bay Project.

This assessment is based on the following:

- Visual inspection of the Mission Bay site
- Review of the available information on the site geology and seismology
- Review of summary soils reports prepared by Dames & Moore
- Brief review of available structural drawings, criteria and architectural renditions
- Engineering judgment and experience



Extensive use was made of EQE's background and knowledge of the performance of soils, structures, foundations, and transportation and utility systems during past destructive earthquakes in developing recommendations to minimize the earthquake risk to the site.

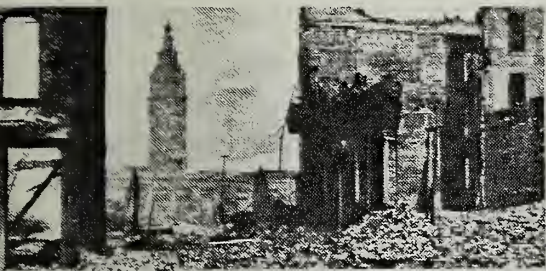
The results present general seismic risk assessments. Detailed engineering studies were not performed. The assessment is intended to identify on a preliminary basis possible problem areas. Detailed engineering reviews may substantially alter the preliminary conclusions once design concepts are finalized.

Major findings and recommendations are summarized by subject area. The subjects summarized include the following:

- Seismic hazard to Mission Bay site
- Risks from seismically induced soil failure
- Risks to buildings
- Risks to lifeline systems
- Earthquake preparedness planning



Seismic Hazard to the Mission Bay Site. The seismic hazard to the Mission Bay site is high due to the close proximity of the San Andreas, Hayward, and Calaveras fault systems, which range from 8 to 20 miles from the site. For the Maximum Credible Earthquake, maximum ground shaking with a Modified Mercalli Intensity of IX (out of a maximum intensity rating of XII - see Table 3-1) is expected due to a Magnitude 8.3 event (which is comparable to the 1906 San Francisco earthquake) centered on the San Francisco Peninsula segment of the San Andreas fault. For the Maximum Probable Earthquake, maximum ground shaking with a Modified Mercalli Intensity of VIII occurs due to a Magnitude 7.0 event on the San Andreas fault. Poorly engineered facilities will suffer significant damage due to these high levels of ground shaking. Well engineered facilities are expected to perform well and to sustain moderate but repairable damage. A detailed discussion of the seismic hazard is presented in Chapter 3.



Risks from Seismically Induced Soil Failures. Several types of seismically induced ground failure have been identified as key concerns at the Mission Bay site. These include soil liquefaction, settlement, and lateral spreading. Liquefaction occurred here during the 1906 earthquake and will likely occur during future large magnitude earthquakes. These types of soil failures can cause severe damage to buildings with inappropriate foundations. However, seismically induced soil failures can also be tolerated by properly designed foundations, as illustrated by the performance of such foundations in many past earthquakes.

Pile foundations are currently envisioned for many of the buildings at the site. This type of foundation provides excellent protection against liquefaction and is strongly recommended to mitigate damage from this hazard. Presently, a wick drainage system is under consideration for parts of the site. A decision on this will be made after this method is measured against other methods such as pile foundations. If a wick system is implemented over large areas of the Mission Bay site, many of the concerns discussed will need to be reassessed for their applicability to the new site conditions.

One to two feet of soil settlement (and locally more) may occur due to soil consolidation under strong ground shaking. Soil will settle away from properly designed pile supported buildings and bridges, leaving the structures in their original positions. Underground utilities will tend to move downward with the soil and may be damaged at their connections to pile supported buildings. Consideration should be given to providing flexibility at the utility-to-building connection to minimize potential damage. Nevertheless, damage to the streets and to underground utilities will be much greater than at other parts of San Francisco with better soils or rock.

Lateral spreading or lurching (horizontal movement as in a landslide) of the soil may occur within 200 feet of the China Basin Channel. To minimize possible damage from this hazard, structural foundations located within this zone should have additional special consideration given to the lateral loads that could be imposed by the soil as it flows towards the open ship channel. If some of the open space which has been proposed is converted to wetlands or a lagoon this will also increase the risk in the area. Special earth retaining provisions may be required.



Access to the Third and Fourth Street drawbridges over the China Basin Channel will likely be severely but temporarily impaired by a combination of soil settlement and lateral spreading. However, it is expected that alternate routes out of the Mission Bay area will be available and temporary loss of access to these bridges should not be a significant problem.

Risks to Buildings. The selection or development of appropriate seismic design criteria for buildings is one of the most important steps in the design or evaluation of a facility. The development of seismic criteria should include consideration of geology, seismology, seismicity, soils engineering, structural dynamics, structural design, earthquake engineering, and experience data from past earthquakes. The *Uniform Building Code* (UBC [1985]) and the *San Francisco Building Code* (SFBC) may not provide an acceptable level of protection for certain facilities. In many cases the UBC does not adequately address specific site locations, site conditions, building configuration, structural set-backs, redundancy, torsion, ductility, differences in stiffness, or adequate design detailing. For example, recent strong earthquakes have shown that UBC seismic requirements for sites on deep, soft soils subjected to strong, distant earthquakes may be inadequate. The UBC is updated every three years. This analysis does not reflect revisions currently under consideration or its next publication in 1988.

Without actually having completed structural drawings of the proposed facilities to review, we can only make general comments on the factors which should be considered during design. Areas which should be specifically addressed are the following:

- **Seismic criteria.** Response spectra for the site should be developed and the requirements of the UBC and/or the SFBC concerning soil amplification should be carefully reviewed.
- **Structural system.** Certain types of buildings tend to suffer more damage in strong earthquakes. Further, the engineering profession has limited experience with the performance of some building systems in strong motion earthquakes. Thus, the construction of certain types of buildings, such as taller concrete frame buildings without shear walls may be restricted. Connection details for tilt-up concrete buildings should also receive additional attention.
- **Peer review of design.** We have found that peer review is a very cost-effective way of reducing risk and improving the design of new buildings. This should be done throughout the design process from reviewing architectural renditions of buildings through checking detailed design calculations. Early involvement of an experienced earthquake engineer will help ensure that adequate consideration is given to factors that are not specified by building codes such as the building geometry and structural system used in the design. By considering how structures with similar





design characteristics have performed during past strong motion earthquakes, undesirable configurations can be modified early in the design process. This will help ensure good performance during a major earthquake.

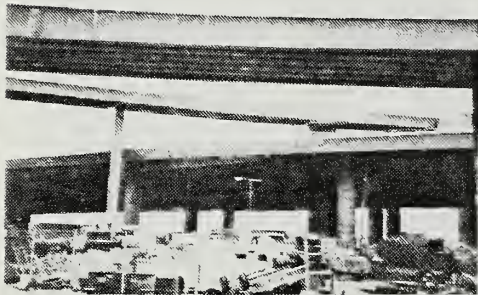
- **Construction quality assurance and control.** Inspection of the building during the construction stage ensures that all detailing is carried out adequately and that construction practices are of the highest quality.
- **Inspection by the design engineer during construction.** Continued involvement of the design engineer throughout the project ensures that construction conforms to the design drawings. In addition, the design engineer can answer any questions or clear up any uncertainties on the part of the contractor.

The seismic hazards at Mission Bay are comparable to those at many other large areas of San Francisco. Figure 2-1 is a general illustration of soil types throughout San Francisco. The buildings at Mission Bay, when completed, will represent the state-of-the-art in earthquake engineering. If the above recommendations are followed, increased safety at a very moderate cost will ensure that the buildings will represent low to moderate seismic risks. That will be in contrast to many other parts of San Francisco where risky older buildings predominate. Overall, the risks for injury from an earthquake to inhabitants of Mission Bay will be lower than most of San Francisco.



Risks to Lifeline Systems. Lifeline systems included in the Mission Bay project include the following components:

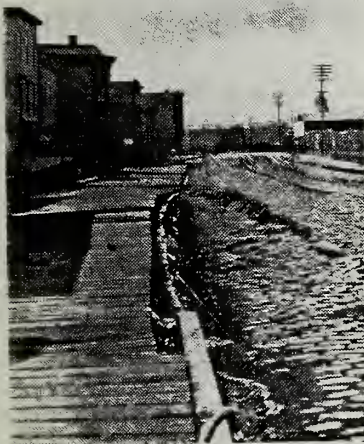
- Electrical power
- Communication
- Gas and liquid fuel
- Water and sewage



The primary risk to lifeline systems (excluding transportation) is due to settlement of site soils and rupturing of utility connections. Historically, underground utilities have experienced damage to connections between pipe sections due to uneven settlement of the ground surface. In addition, the utility interface with pile supported structures has also proven to be a problem area since utilities move downward with the soil and tend to fail at their connection to the unmoving structure. Considerations should be given to providing flexibility at the building-to-utility connection.

Extensive experience data on the performance of underground pipes exist. The experience points out clearly that certain types of pipe are more vulnerable to settlement. For example, for communications conduit, steel conduit perform much better than polyvinyl chloride conduit. Ductile iron and steel pipes perform much better than cast iron or concrete pipes for potable water and waste water applications. It is recommended that the City of San Francisco carefully consider the design of the underground facilities and retain consultants to ensure maximum application of current knowledge.

Preparedness Planning. Because of the somewhat isolated nature of the Mission Bay site, special consideration must be given to egress from and access to the site, both by residents of the area, those who are employed in the area, and emergency personnel. The potential problem areas which were investigated include the following:

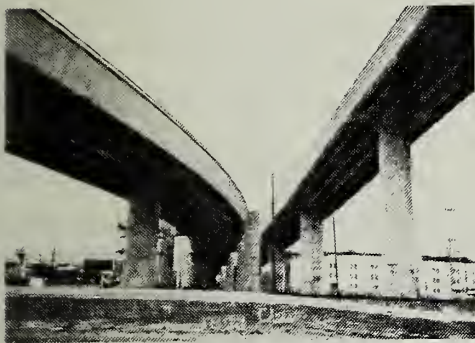


- **Performance of the elevated highways** which run along portions of the perimeter of the site. It is likely that the elevated highways will suffer considerable damage. Given the redundancy of the existing interchange structure and the performance of similar structures during past earthquakes, we consider it a very remote possibility that general collapse of the interchange would occur blocking all access. The elevated highways themselves may not be usable, but this will not block access to and egress from the Mission Bay site. Surface streets may suffer damage, but should be passable by emergency vehicles or light trucks (see adjoining illustrations of 1906 street damage).
- **Performance of the Third Street Drawbridge.** This bridge is not expected to collapse, although some deformation of the structure may occur so that the bridge will not open to traffic. In addition some settlement of the soils abutting the bridge would occur, making the approach to the bridge unpassable.



- **Performance of the Fourth Street Drawbridge.** This bridge has a high likelihood of being damaged during an earthquake and will probably not function properly, although passage may be possible. There will be significant ground settlement at the approaches and fill would have to be brought in to provide temporary access if the bridge is passable.
- **Performance of the electrical system.** Damage to both distribution and transmission systems is to be expected and emergency generators should be provided at important facilities. Damage will be minimized through the anchoring of equipment.
- **Performance of the communications system.** All vital telecommunication equipment should be braced and anchored before the event to minimize damage. Because most of the distribution lines consist of buried cables, damage should be expected.
- **Performance of gas pipelines, water, and sewage systems.** Large ground displacements will result in damage to all of these systems. This damage can be lessened by providing flexible connections to buildings and other structures and by providing as much redundancy in the system as possible.

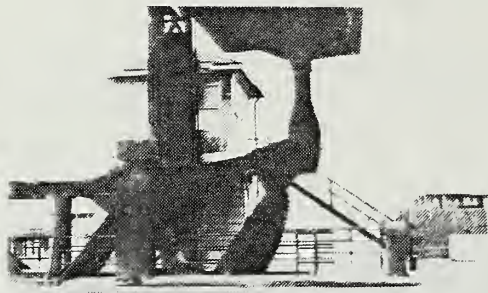
2.2 Recommendations



In the previous section, key seismic concerns for the site were summarized along with recommended approaches to minimize the resulting earthquake risks. These approaches will need to be modified as appropriate when the overall land use planning for Mission Bay is finalized. Specific recommendations to reduce the risk to the Mission Bay site will depend to a large extent on the type of foundation systems, structural systems, and overall site layout used in the final design.

To ensure the Mission Bay site represents a low risk during a major earthquake, the following steps should be implemented:

1. Establish a formal policy for constructing an earthquake resistant development at the site. This would include reviewing the adequacy of proposed seismic criteria and establishing a quality assurance program including independent design review for new design and construction.
2. Provide for the continued involvement of a seismic consultant throughout the development and implementation of all major phases of the project to review the seismic adequacy and implications of proposed construction based on a complete parcel-specific evaluation of soil conditions. Ongoing involvement of this consultant throughout the review process will ensure designs have adequate consideration of seismic performance early in the review process and avoid expensive modifications late in the design.



Provide for a review of the adequacy of central lifeline systems serving the Mission Bay area, and connections with individual buildings developed on the site, in terms of materials and construction methods to withstand extensive damage from a major seismic event and consistent with requirements for city building permits.

3. If a transportation plan is chosen which has only one major street with access under I-280, a detailed engineering analysis of the highway should be performed to quantify the risk to the highway. As long as there is more than one surface street with access under the elevated highways, access to and egress from the area will not be a problem immediately following the earthquake.
4. It may be possible to regain access across the Third and Fourth Street drawbridges if earthquake preparedness planning includes the provision of fill material (perhaps as part of an earth berm within nearby open space areas) to rebuild temporary bridge approaches to permit emergency access.

3. SEISMICITY

Site conditions in the Mission Bay Project area were reviewed to determine the site specific seismic hazards. The assessments included (1) a review of summary soil reports prepared by Dames & Moore to determine in situ conditions and (2) identification of major faults in the area likely to affect the site. Consideration was given to historical records of fault activity and site soil conditions in developing expected ground shaking intensities and assessing the potential for significant soil failures, such as liquefaction or settlement, during strong ground shaking.



This chapter summarizes the site specific seismic hazards for the Mission Bay site reviewed during this survey. Site specific seismic hazards of concern include:

- Level of expected ground shaking
- Potential for seismically induced soil failure

Each of these hazards is discussed below.

Additional general information concerning the overall seismic hazard in the San Francisco Bay Area is presented in Appendix A. This appendix includes a discussion of general earthquake terminology, a brief summary of the earthquake history of the San Francisco Bay region, and a description of major faults expected to affect the Bay Area.

3.1 Site Description

A plan view of the Mission Bay site is shown in Figure 3-1. It is triangular shaped and is approximately bounded on the west side by Seventh Street, on the north side by Townsend Street, and to the east by China Basin Street. The northern third of the site is separated from the remainder of the site by China Basin Channel. North-south access between these two areas is provided by drawbridges at Third and Fourth Streets.

As shown by Figure 3-1, most of the Mission Bay site is filled land that is exterior to the 1853 shoreline. Fill materials are random in nature and are underlain by soft bay mud up to 120 feet in thickness. It is thought that most fill material was placed between 1865 and 1906. Some of the site may have been used as a refuse dump and as a repository for debris from the 1906 earthquake.

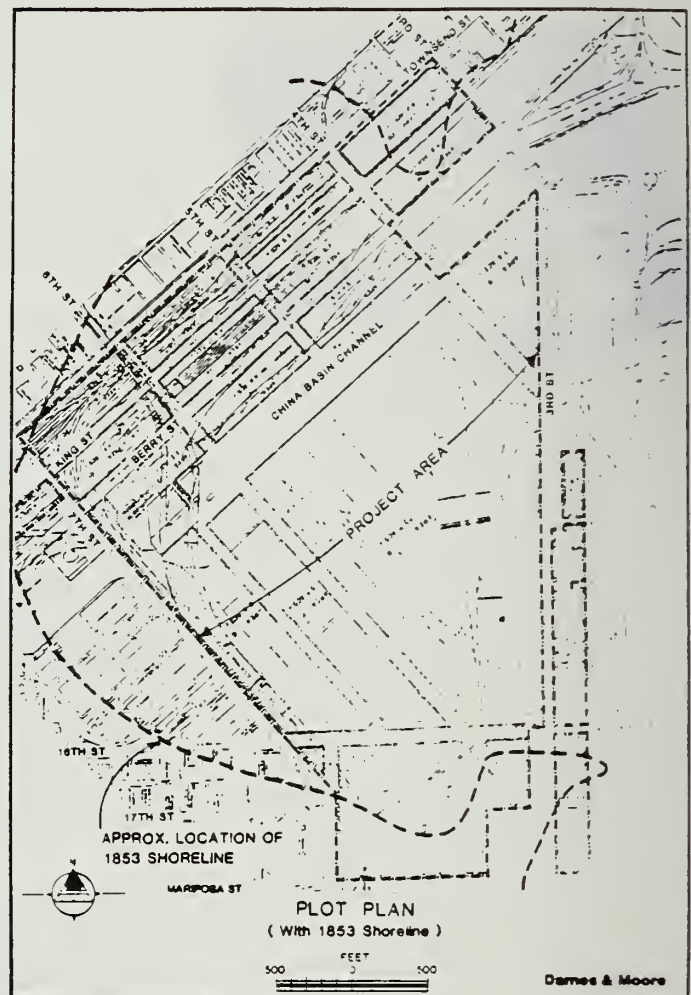


Plate 1

Figure 3-1: Plan View of Mission Bay Site Showing Approximate Location of 1853 Shoreline (Reference 13)

3.2 Earthquake Ground Shaking

The most significant hazard resulting from an earthquake is ground shaking. This is due to the large area affected by a major earthquake, the consequent potential for widespread damage, and secondary effects that may occur such as ground liquefaction or settlement.

Earthquake ground shaking is usually described in terms of intensity. Intensity relates directly to observed damage and depends on the distance from the fault rupture to the site and local geologic conditions. The 1931 Modified Mercalli Intensity (MMI) scale shown in Table 3-1 is most commonly used to describe intensities.

There are several active faults in the Bay Area capable of causing strong ground shaking at Mission Bay. The locations of these faults relative to the project are shown in Figure 3-2.

Expected seismic intensities at the Mission Bay site were developed for two levels of earthquakes. These are:

- A Maximum Credible Earthquake (MCE) representative of the strongest ground shaking that could occur at the site.
- A Maximum Probable Earthquake (MPE) representative of the strongest ground shaking that is likely to occur in the near future.

The MCE is defined as a severe event having an approximate probability of exceedance of 10% during the next 50 years. This corresponds to a return period of approximately 500 years and represents a reasonable upper bound on the expected level of ground shaking. Ground shaking experienced during the 1906 San Francisco earthquake is representative of expected MCE intensities.



The MPE is defined as a more moderate event having a 50% probability of being exceeded within the next 50 years. This corresponds to a return period of about 50 years.

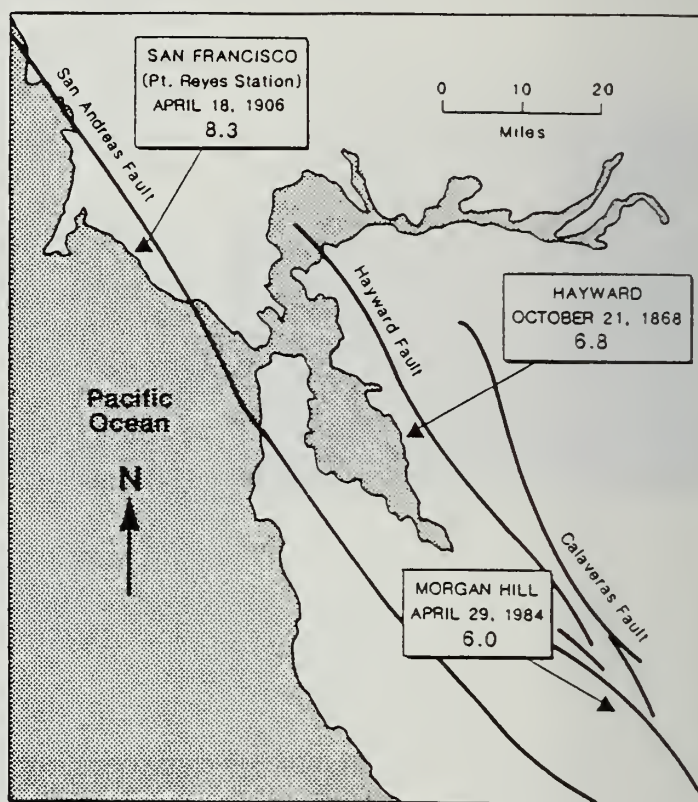


Figure 3-2: Mission Bay Site Relative to Major San Francisco Bay Area Faults.

Table 3-1
MODIFIED MERCALLI INTENSITY SCALE

- I. Not felt. Marginal and long-period effects of large earthquakes.
- II. Felt by persons at rest, on upper floors, or favorably placed.
- III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
- IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.
- V. Felt outdoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
- VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Window, dishes, glassware broken, knickknacks, books etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visible, or heard to rustle).
- VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
- VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B, none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
- IX. General panic. Masonry D destroyed; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
- X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks to canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
- XI. Rails bent greatly. Underground pipelines completely out of service.
- XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Source: Richter, C.F. Elementary Seismology. San Francisco CA: W. H. Freeman Co., 1957.

Note: To avoid ambiguity, the quality of masonry, brick, or other material is specified by the following lettering system. (This has no connection with the conventional classes A, B, and C construction.)

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses, like failing to tie in a corner, but neither reinforced nor designed to resist horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.



The three faults likely to cause the strongest ground motion at the Mission Bay site are the San Andreas, Hayward, and Calaveras fault zones. Table 3-2 summarizes expected ground shaking intensities in the Mission Bay area due to both an MPE and an MCE occurring along these faults. Results indicate the controlling MCE is along the San Andreas fault. The maximum expected MMI at the site is IX. The MCE event on the Hayward fault would produce nearly the same intensity of ground motion.

These high intensities are also due to the nature of the soils at the site. The site soils consist primarily of random fill material which is underlain by 30 to 120 feet of natural bay mud. Soft soils such as these typically show higher amplification of ground motion than that which would be experienced at a rock or stiff soil site.

The hazards and the resulting risks to the Mission Bay site are typical for several large areas of San Francisco. For example, similar hazards exist for most of the northeastern and eastern shoreline areas of San Francisco, including the Marina, Fisherman's Wharf, the Financial District bounded by Telegraph Hill, the Bay Bridge approaches, and The Embarcadero and Montgomery Streets, much of the area south of Mission Street extending to Hunters Point, and San Francisco International Airport (see Figure 2-1).

Similarly, for the MPE, maximum expected ground shaking at the site is due to an earthquake along either the San Andreas or Hayward faults. The expected MMI due to either of these events is VIII.

Table 3-2
Maximum Expected Intensities at the
Mission Bay Site

Fault	Minimum Distance to Fault (miles)	<i>MCE</i>		<i>MPE</i>	
		Magnitude	MMI	Magnitude	MMI
San Andreas	8.5	8.3	IX	7.0	VIII
Hayward	10.0	7.5	VIII-IX	6.8	VIII
Calaveras	20	7.0	VII	6.4	VI

3.3 Seismically Induced Soil Failures The principal types of soil failure that may occur at the Mission Bay site due to a major earthquake are liquefaction, lurching and lateral spreading, and settlement. These hazards are site specific and depend on distance to the fault, intensity of expected ground shaking, height of the existing water table, foundation type, and type of soil. Other hazards such as surface faulting and seismically induced landsliding are not a concern for this site.

Liquefaction is the sudden loss of bearing strength that can occur when saturated, cohesionless soils (sands and silts) are strongly and repetitively vibrated. Liquefaction typically occurs in loose sand deposits where there is subsurface ground water above a depth of 20 feet.

Lurching and lateral spreading are similar phenomena caused by liquefaction in some subsurface horizon. The overlying ground as far away as 100 feet moves laterally toward a free surface such as a canal bank or drainage ditch. The ground surface may be virtually flat in areas where this occurs.

Settlement or compaction of loose soils and poorly consolidated alluvium can occur as a result of strong seismic shaking, causing uniform or differential settlement of building foundations. Buildings supported on deep (pile) foundations are more resistant to such settlements. The Ferry Building survived the 1906 earthquake because it was built on such foundations (current design methods call for much more sophisticated and earthquake resistant details than were used in the Ferry Building). Other types of foundations may also be appropriate, depending on the building type, configuration, function, and occupancy.



Historical Seismic Ground Failures at the Site. One of the heavily damaged areas in San Francisco in 1906 was the area between Fourth and Eighth Streets, between Mission and Townsend Streets, immediately north of the Mission Bay Project area. Liquefaction, lateral spreading and differential settlement occurred throughout this area and damage was severe.

By contrast the Mission Bay area saw few reports of damage. Various reasons for this discrepancy have been offered. The most credible one is that there were few developments and therefore no heavy loads existing at the time in the Mission Bay area and the few that did exist were either light construction or had well ballasted foundations such as the railroad yards. Another explanation is that perhaps the Mission Bay fills were constructed with better materials containing more broken rock from Potrero Hill.

Some damage was noted, however, within the site. The drawbridge at Third and Channel Streets was damaged; four inches of soil settlement occurred. In addition, a number of bricks on Townsend Street settled about two feet below the railroad right of way.

At several locations in the area north of Townsend Street, severe ground cracking and deformation were reported on three occasions following earthquakes: in 1865 (San Andreas fault, M6.5); 1868 (Hayward fault, M6.8); and again in 1906. This argues against the idea that soil conditions may have been improved by densification and settlement incurred in previous earthquakes.



Another area that was severely damaged in 1906 was the former Mission Creek fill area located several blocks west of the site at the present interchange between the James Lick Freeway and the Central Skyway. The mode of failure was slumping and lateral spreading. Lateral deflections of street car tracks and curbs were as much as 6 to 8 feet. Sewer lines and manholes were disrupted and punched up out of the pavement. Most structures were badly damaged but few collapsed.

Hazard Evaluation Findings. The results of our evaluation of the level of risk posed by seismically induced soil failures are presented in Table 3-3. The primary concern is the possibility of liquefaction and lateral spreading in the area generally north of the China Basin channel and widespread settlement throughout the site area. Summary soils reports by Dames and Moore indicated that the surface layer is tandem dumped fill and rubble. Very poor garbage landfills may exist but were not reflected in the site investigations. The underlying soils consist of very compressible thick bay mud; therefore differential seismic settlement is the principal hazard.

Table 3-3
Level of Risk Posed by
Seismically Induced Soil Failures

Hazard	North of China Basin Channel	South of China Basin Channel
Liquefaction ¹	High	Low to High (depending on local soil conditions)
Lateral Spreading ¹	Moderate to High	Moderate
Differential Settlement ¹	Moderate to High	Moderate to High

¹ Risk level assumes existing site conditions with no corrective geotechnical measures (e.g., densification of soils)

The following types of damage are anticipated to result from the MCE (less severe damage would occur due to an MPE):



- Widespread area settlements and locally concentrated differential settlements up to two feet for shallow foundations with no special seismic design provisions.
- Local severe disruption of pavement rendering some sites temporarily inaccessible except by four-wheel drive vehicles or light trucks.
- Disruption of underground utility pipes and lines at the point where they enter the building foundation. This applies even for well engineered structures on deep piles unless flexibility is designed into the utility lines.
- Extensive ground cracking and architectural damage to surface mounted non-building structures.
- Liquefaction and local lateral spreading of two feet maximum, especially adjacent to canals and in the whole area north of China Basin channel if soil densification is not performed. Lateral spreading related to canals could extend outward several hundred feet from the channel.
- Channel bank slumps and possible rotation and damage to old retaining walls would be expected along the China Basin Channel.
- Pile foundations for the Third and Fourth Street bridges should perform well. However, access to the bridges may be

impaired due to settlement of the bridge approaches.

Most of the damage described above could be mitigated by extensive earthwork and foundation engineering; for example, densification with surcharge fills, upgrading of inadequate foundations, and retaining walls. Such measures will require economic cost/benefit studies to determine the extent of feasible mitigation of the soil failure hazards. In our opinion, however, most such measures are not cost effective.

One additional consideration is the possibility that the existing China Basin Channel may be extended or modified into a lagoon. While additional lagoons and channels would enhance the aesthetic and environmental qualities of the project, they would also increase the seismic risks and have some negative economic impacts.

The following recommendations were made in the Dames and Moore report:

1. Densify zones 200 feet wide on both sides of all channels.
2. Line all channels with 6-foot high retaining walls and grade channel bottom slopes to 4:1 (H:V) or shallower.
3. Set buildings back from channel edges an unspecified distance.

Thus, construction of additional channels increases the amount of stabilization and remedied earthwork required for the project and decreases the land space available for development more than the plan outline area of the lagoon would indicate. In addition, the risk of lateral spreading damage and bank failures would be increased by construction of lagoons.



At the present time, a wick drainage system is under consideration to preconsolidate selected areas of the site in order to reduce the need for pile foundations. A decision on this will be made after that alternative is measured against other alternatives, such as pile foundations. If this system is implemented over large areas of the Mission Bay site, many of the concerns discussed above will need to be reassessed for their applicability to the new site conditions.

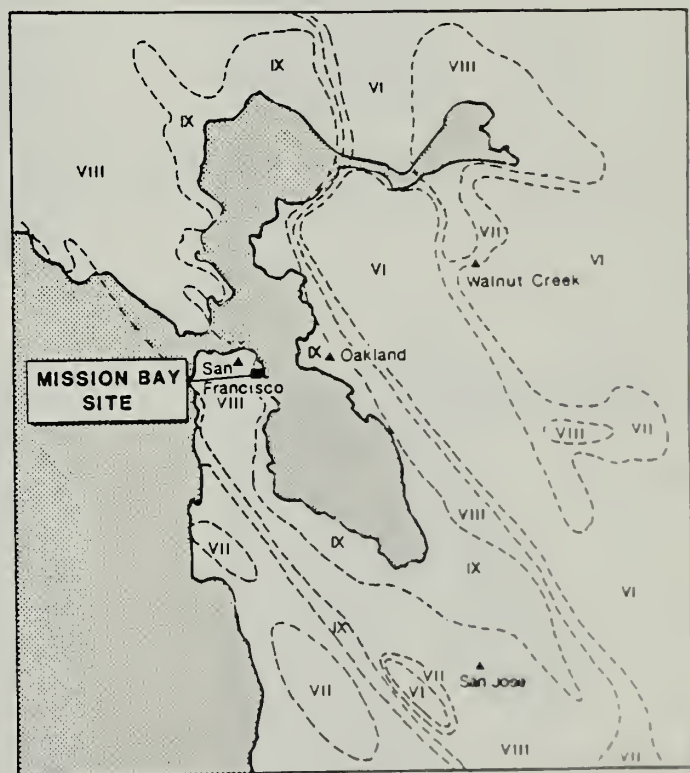


Figure 3-3: Modified Mercalli Intensity Distribution for an MCE ($M=8.3$) on the San Andreas Fault.

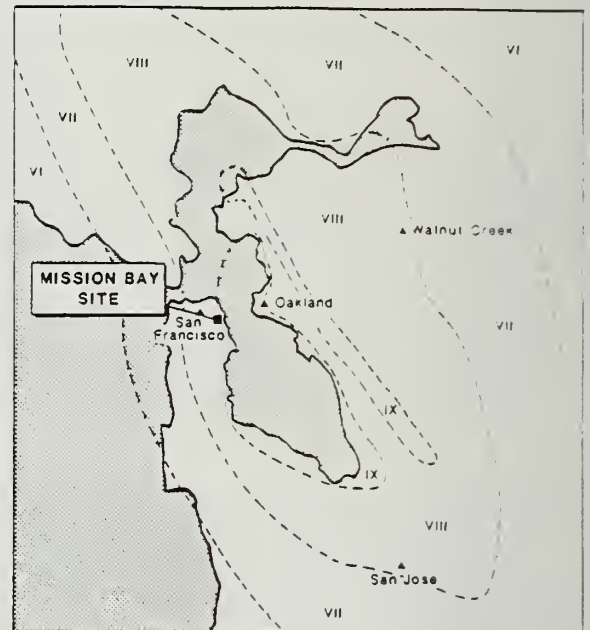


Figure 3-4: Modified Mercalli Intensity Distribution for an MCE (M=7.5) on the Hayward Fault.

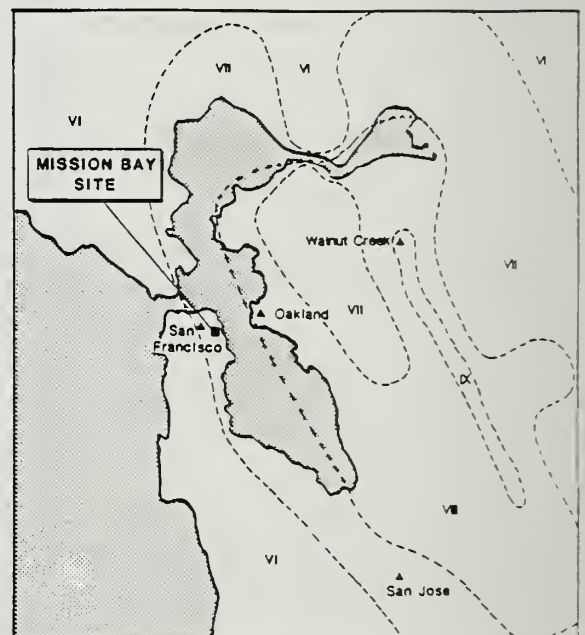


Figure 3-5: Modified Mercalli Intensity Distribution for an MCE (M=7.0) on the Calaveras Fault.

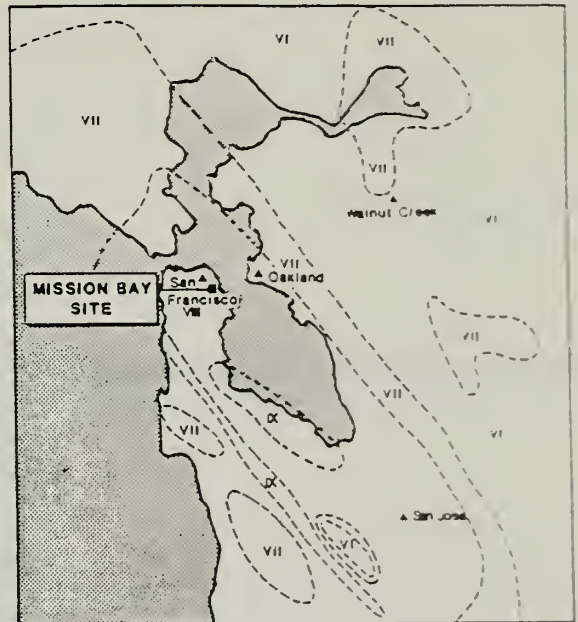


Figure 3-6: Modified Mercalli Intensity Distribution for an MPE (M=7.0) on the San Andreas Fault.

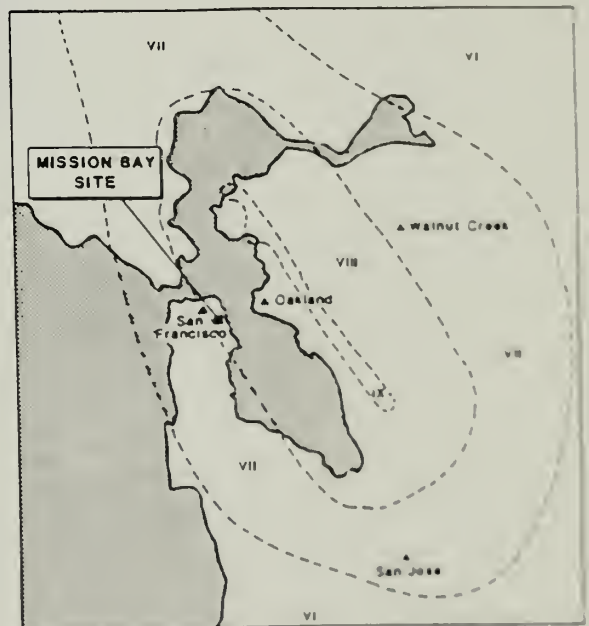


Figure 3-7: Modified Mercalli Intensity Distribution for an MPE (M=6.8) on the Hayward Fault.

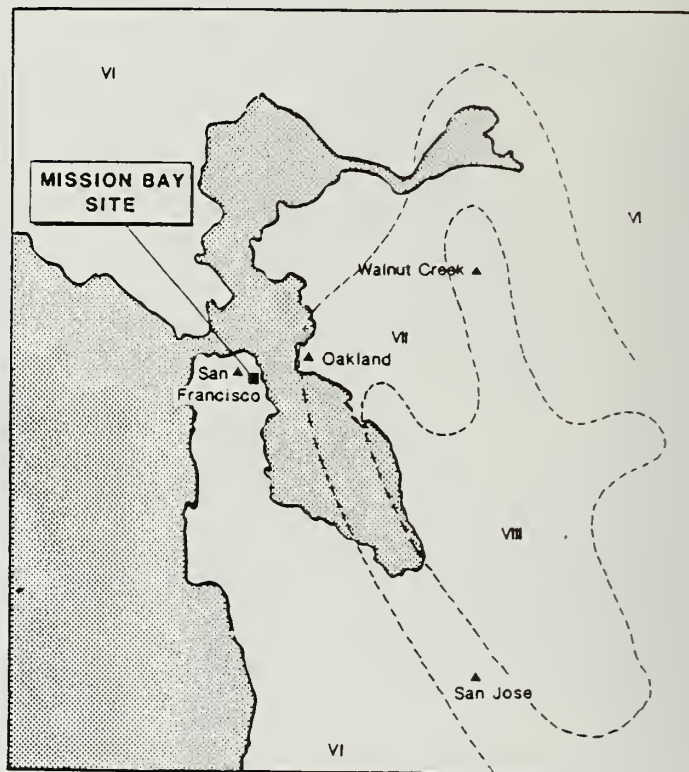


Figure 3-8: Modified Mercalli Intensity Distribution for an MPE (M=6.4) on the Calaveras Fault.

4. BUILDINGS

4.1 Introduction

Table 4-1 summarizes the planned land uses for the nearly 300 acre Mission Bay site. Housing is currently being planned to occupy about 30 to 43% of the land. It is anticipated that about 60% of the area will be used for construction of buildings in the various non-residential categories. Therefore, much of the site will be occupied by buildings of various types.

Because planning is currently at an early development stage, no structural types, configurations, or details have been set forth for buildings in the various land use categories. However, prototypes of buildings in some of the land use categories have been presented by others. Housing prototypes have been suggested in *Choices for Mission Bay* (Reference 1). Prototypes for office, retail, and research and development facilities are provided in Reference 11. Because the project is in an early development stage, there are no structural drawings available for review.



4.2 Building Types

Although the design concept has not been finalized, it is expected that the following types of structures will be included at the site.

Housing. Housing will basically consist of low-rise and mid-rise construction with some additional housing provided by houseboats in China Basin Channel. Low-rise housing consists of three stories of wood-frame housing over a parking garage in some areas and four stories of wood-frame housing over a garage.

Mid-rise housing consists of eight stories of housing over a parking garage. Other options would include housing above offices or retail facilities. These buildings would be steel or concrete frame with reinforced concrete garages and pile foundations.

Table 4-1
Mission Bay Land Use Program Range

<u>Use</u>	<u>Acres</u>	<u>% of Total Available Land</u>
Housing	88 - 126	30 - 43
Public Open Space ¹	72 - 99	24 - 33
Office	10 - 45	3.4 - 15
R&D	12.8 - 38	4.3 - 13
Retail	7.2 - 16	2.4 - 5.4
Maritime	0 - 45	0 - 15
Hotel	3.5 - 4	1.2 - 1.4
Community Facilities	1.2 - 3	0.4 - 1.0
Infrastructure and Misc.	62 - 69	21 - 23
TOTAL	176 - 372	

Notes:

1 Includes public open space within housing, officer and R&D acreage.

2 Total available land = 295 acres

Source: *Adapted Choices for Mission Bay* (Draft), June 11, 1986

Retail Use. Various alternatives exist for retail facilities. Primarily, retail use will be integrated into other structures, particularly housing and offices.

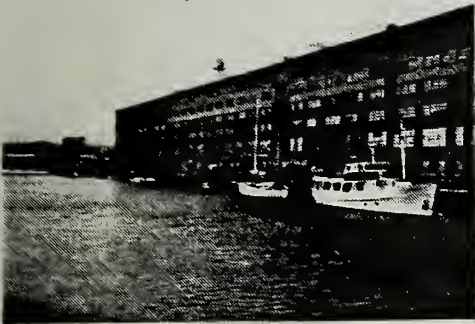
Office Buildings. Office buildings will be predominantly eight stories in height with accompanying parking. The structural system would be either steel or concrete with pile foundations.

Research and Development. Five types of R&D facilities have been proposed, ranging in height from two to four stories. Buildings may be of concrete tilt-up, shear wall, concrete frame or steel construction. Parking will be provided for all types.

Community Facilities. Specific needs of the Mission Bay area for community facilities must be analyzed before settling on a program for these services. Among those facilities to be considered are the following:

- Police
- Fire station
- Schools
- Public health
- Emergency services
- Childcare
- Cultural arts facilities
- Recreation
- Libraries
- Community center

The structural system and design criteria used will depend primarily upon the importance and safety requirements for the facility.



4.3 Historical Performance of Buildings in Earthquakes

Past earthquakes and current analytical tools give us the experience from which we can predict the performance of typical building types.

Wood-frame buildings, when properly designed and constructed, are highly resistant to damage from earthquakes. Problems tend to occur when the buildings are geometrically complex, have too many large wall openings, or are not well maintained.

Concrete tilt-up buildings (for offices and other commercial uses) have been one of the most hazardous new industrial structures in strong earthquakes. These buildings are called "tilt-up" because the exterior concrete walls are formed and poured in a horizontal position and subsequently lifted and tilted into place with a crane. The concrete tilt-up came into general use in the early 1960s and is still one of the least costly types of industrial structure.

In 1971, concrete tilt-up buildings were subjected to a moderately large earthquake for the first time. The San Fernando Valley earthquake of February 9, 1971 (M6.5) caused extensive damage, and numerous industrial tilt-up buildings partially collapsed. Following this poor performance, the seismic requirements of the *Uniform Building Code* (UBC) were increased in 1973. The 1976 and 1979 UBCs were again revised to include more stringent requirements.

One of the primary reasons for the poor performance of the tilt-up buildings was inadequate roof-to-wall connections. When good design, detailing and construction practices are used, it is expected that tilt-up buildings built to the later UBC codes will perform adequately in a moderate or stronger earthquake.



Steel-frame structures that are well designed and constructed tend to be the most earthquake-resistant buildings. This is because of their light weight and their ability to be damaged extensively without collapse. Problems arise when the building is geometrically complex, important bracing details are missing or inadequate, and the building is too flexible.

The performances of cast-in-place concrete, concrete block, and masonry buildings in strong earthquakes are generally more difficult to assess without evaluating design and construction details. Historically, concrete shear wall buildings with properly detailed shear walls have performed well and can be good alternatives to steel buildings. Non-ductile concrete frame structures have performed poorly in past earthquakes. Many of the buildings that collapsed in Mexico City during the 1985 Mexico earthquake were of this type.



The use of non-ductile concrete frame buildings in regions of high seismicity must be avoided. In fact, the UBC requires the use of ductile concrete detailing in all except the lowest seismic risk zones. However, it is recommended that any pure concrete frame buildings without shear walls be avoided.

4.4 Design Criteria

Recent earthquake engineering research and data on building response during past earthquakes have provided a clearer understanding of the performance of materials and structural elements during earthquakes. Much of this increased knowledge is reflected in modern building codes. However, designing facilities to be in full compliance with building codes does not guarantee satisfactory performance of structures during major seismic events.



The most widely used code in high seismicity regions of the United States is the *Uniform Building Code* (UBC). San Francisco has adopted a code slightly more stringent but very similar to the UBC.

Building codes are intended to set minimum requirements for earthquake resistance of ordinary structures. For such structures it provides the designer with a general method of assessing seismic response loads and designing in a somewhat consistent manner to some minimum standard. The intent of the code is to safeguard against major failures and loss of life.

The strict application of the code to all sites and all types of structures may result in designs that can have major weaknesses. This is particularly true if the site has special geotechnical considerations making it a high seismic risk or if buildings have unusual or irregular design features.

We consider Mission Bay to be a high seismic risk site. The soft soils at the site may result in significant local amplification of ground motion. It was observed during the 1985 Mexico earthquake that buildings 5 to 15 stories tall founded on a similar site resonated with the earthquake ground motion and experienced seismic loads significantly exceeding those anticipated by the building code. A number of poorly engineered buildings in this height range collapsed.

Some of the building types proposed for Mission Bay are in the 4 to 8 story range. While it is not anticipated that collapse would occur during a major earthquake for well designed and constructed structures, severe structural damage is a possibility if a minimum code level design is used, particularly if the intent of the code is not met.

Therefore, it is strongly recommended that site specific seismic design criteria be developed for the Mission Bay site. Well developed design criteria will ensure that seismic risk to structures and equipment is minimized, consistent with desired performance objectives. It is envisioned that this criteria document will be based on the City of San Francisco Building Code with appropriate enhancements to address site specific concerns and goals for the performance of facilities at the site.

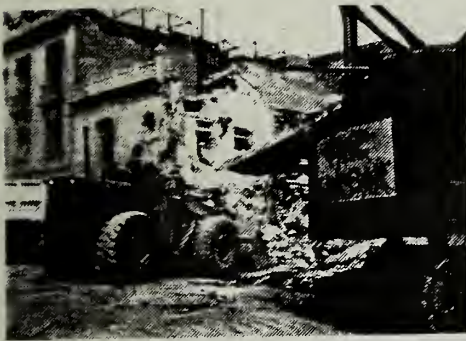


The development of site specific seismic design criteria should include consideration of geology, seismology, seismicity, soils engineering, structural dynamics, structural design, earthquake engineering, and experience data from past earthquakes. Other issues which should be addressed include building configuration, structural set-backs, redundancy, torsion, ductility, differences in stiffness, and adequacy of design detailing. The degree of sophistication of such criteria primarily depends upon the importance of the facilities being designed.

The seismic hazards at Mission Bay are comparable to those at many other large areas of San Francisco. If the above recommendations are followed, increased safety at a very moderate cost will ensure that the buildings will represent low to moderate seismic risks. That will be in contrast to many other parts of San Francisco where risky older buildings predominate. Overall, the risks for injury from an earthquake to inhabitants of Mission Bay will be lower than most of San Francisco.



5. INFRASTRUCTURE PERFORMANCE



Important components of the Mission Bay infrastructure which could be of concern following a major earthquake include transportation systems such as freeways, surface streets, bridges, railroads(including Muni), and port facilities. In addition, lifeline utility systems including telephone, electricity, gas, water, and sewage should be designed to minimize damage and survive a major earthquake relatively intact.

The purpose of this chapter is to briefly review the proposed infrastructure of the Mission Bay site to determine potential risks. General recommendations to minimize risk of significant damage or isolation of the site during a major earthquake are presented as appropriate.

5.1 Transportation Systems

Key components of the transportation system currently envisioned for the Mission Bay site include the I-280 freeway, surface streets, the Third and Fourth Street drawbridges, and various forms of public transportation. Adequate access to the site following a major earthquake will depend on good performance of several of these components.

Post-earthquake survival of the transportation infrastructure is important in order to allow adequate access to the site for the following:

- Medical teams and supplies to quickly reach the earthquake stricken area
- Fire-fighting equipment, reconstruction equipment, and earth moving equipment to rapidly access heavily damaged or burning facilities
- Police or National Guard to move in and protect local businesses and residences from looting

- Disaster relief agencies, such as the Red Cross, to distribute food, water and clothing

Based on past experience, egress and entry to an area following a major earthquake is normally not a significant problem. Even if roads or bridges are temporarily blocked, people will use alternate routes to bypass heavily damaged areas. Heavy equipment can be rapidly mobilized to remove debris blocked roads.



A concern at the Mission Bay site is whether the project can be isolated from the remainder of San Francisco by the simultaneous collapse of the I-280 overpass along the west side of the site and failure of the Third and Fourth Street bridges. As discussed below, this is not considered a significant problem. Historical performance of elevated highway systems demonstrate that collapse is very unlikely, particularly for redundant structures such as this portion of I-280.

Surface Streets. Surface streets in the Mission Bay area will probably experience varying amounts of damage from soil related failures. During the 1906 San Francisco earthquake, considerable damage occurred to roads in the Mission District because the roads were built on top of poorly engineered land fill (see adjacent photos). Damage to streets in the Mission Bay area will likely consist of the following:

- Settlement of approach sections to bridge abutments. Access to the bridges will likely be temporarily impaired due to settlement of soil away from the pile supported bridges.
- Warping and fracturing of pavement due to uneven settlement and lurching of the soil.

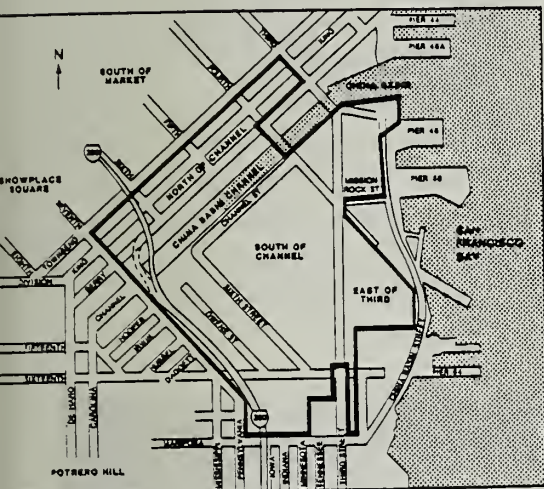


Figure 5-1: Location of I-280

Although surface streets may experience considerable damage during a major earthquake, they should still be passable to light trucks and four-wheel drive vehicles. Additionally, a well-designed network of streets offers many alternate routes if some streets are impassable. During an emergency, usage could be restored within a short period of time through the use of heavy equipment.

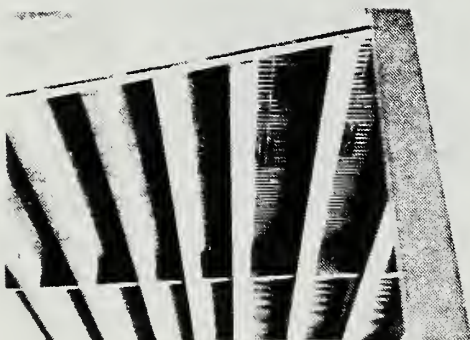
Elevated Highways. During the San Fernando earthquake of 1971, several elevated highways collapsed onto the freeways below, blocking portions of the freeway. One of the concerns at the Mission Bay site is whether the segment of Interstate 280 paralleling the western edge of the site could collapse completely blocking entry and egress from the area.

As shown by Figure 5-1, Interstate 280 passes along the western portion of the Mission Bay site. The highway crosses Sixteenth Street on the southern side of the site and Townsend Street on the northern side.

This portion of Interstate 280 was constructed in two segments. According to Caltrans, the bridge foundations and columns of the first segment between Mariposa and Brannan were completed prior to the 1971 San Fernando earthquake. The design of this section was approved in 1969.

The second segment between Third and Sixth Streets was built during the early 1980s. It is currently anticipated that this portion of the freeway will eventually be removed during the development of Mission Bay.

Structural drawings of the original freeway segment indicate that it is constructed from pre-cast, prestressed beams that span between the support frames. Supporting frames have either two or three columns. The foundation consists of H-piles with pile caps with piles normally driven to bedrock. There are no batter piles to carry lateral earthquake loads.

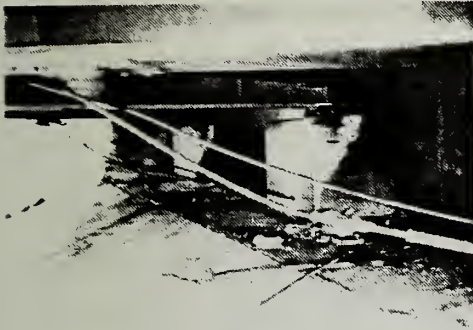


This structure was designed to resist earthquake forces in accordance with the requirements of the 1965 edition of the *American Association of State Highway Officials Code* and as supplemented by Caltrans' *Bridge Planning and Design Manual*. Seismic criteria in these documents have been substantially revised since that time. These changes reflect experience gained from the 1971 San Fernando earthquake.

During this earthquake, approximately 62 bridges in the epicentral region suffered varying amounts of damage from minor cracking and spalling to total collapse. About 25 percent of the bridges sustained severe damage or totally collapsed, 50 percent were moderately damaged, and the remaining 25 percent suffered minor damage. Multicolumn bridges generally suffered less damage than single column bridges. All of the damaged bridges were designed in accordance with the seismic code requirements in place at that time.

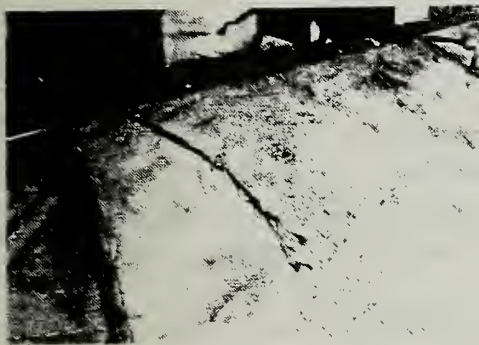
Post-earthquake investigations concluded that the majority of the damage to the bridges was attributed to shortcomings in the design details. A number of improvements to the building codes were recommended as a result of these studies. Code changes were designed to improve the ductility of bridge column members and ensure that the structure acts as a unit.

Immediately following this earthquake, improved seismic design details were incorporated into California freeway bridges currently under construction or in the final design stages. According to Caltrans, these details were not incorporated into this portion of I-280 because much of the construction had been completed by the time the earthquake occurred.



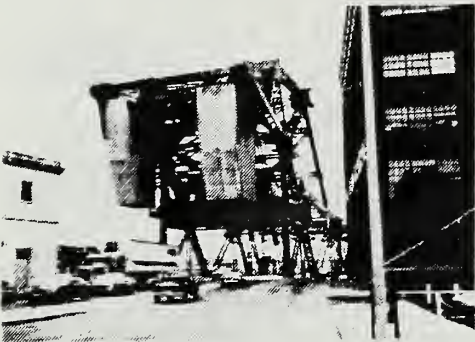
However, Caltrans has also implemented a seismic retrofit program for existing bridges lacking adequate seismic details. In about 1981, this section of the freeway was seismically retrofitted by tying the decks together across supports through the use of heavy steel rods. The philosophy of the seismic retrofit is to allow some damage to occur but prevent partial or total collapse during a major earthquake.

There is some question as to how well these retrofits will perform. During the 1986 Palm Springs earthquake ($M=5.9$), the Whitewater Overpass on Interstate 10 suffered extensive damage to the seismic retrofit system. The retrofits used at this bridge are similar in design to those used on I-280. The bridge did not fail but it is currently unclear as to what would have happened if an earthquake with a longer duration (such as a 1906 type earthquake) had occurred.



Based on the above considerations and other historical data, the elevated portion of I-280 at the Mission Bay site is expected to be significantly damaged during a strong earthquake but should not experience general collapse. In the unlikely event that local collapse should occur, there is a low probability that it would block access into the area provided that more than one street exists.

Currently, 16th Street is the only surface street providing direct access to the west side of the site south of the China Basin Channel. When finalizing the site layout, additional surface streets should be planned to go underneath Interstate 280. By having several alternate routes available out of the area, it is very unlikely that all of them would be blocked following an earthquake. As an alternative, if only one street will be passing beneath the elevated portion of I-280, it is recommended that a detailed seismic analysis be performed for the freeway section directly above the street.



Third and Fourth Street Drawbridges. Draw (or bascule) bridges are located across the China Basin Channel at Third and Fourth Streets. Both are of steel truss construction and depend on heavy reinforced concrete counterweights to provide the weight required to operate their cantilever lifting mechanism.

The Third Street bridge, called the Francis "Lefty" O'Doul Bridge, was designed in 1932. The bridge is supported on three concrete piers on wood piles. Both vertical and batter piles were used. The bridge has a span of 142 feet and a width of about 80 feet. The approach structure on the south side of the bridge is constructed of a reinforced concrete slab and girders and is supported on vertical concrete piles.

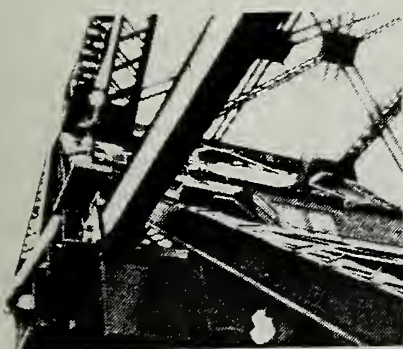


The Fourth Street bridge, designed in 1915, is called the Peter R. Maloney Bridge. It is 61 feet wide and has a span of about 205 feet. The bridge is supported on two piers on vertical and battered wood piles. Bridge abutments are also supported by vertical and battered wood piles.

Both drawbridges were extensively analyzed in 1984 as part of a seismic evaluation program for City of San Francisco bridges. The evaluation involved state-of-the-art computer analyses using 1984 ASHTO design criteria.

Evaluation results for the Third Street Bridge concluded that the bridge had sufficient capacity to resist the lateral earthquake loads and that strengthening was not required to prevent collapse. Some rehabilitation work was recommended to repair deterioration of the reinforced concrete piers.

However, it was also concluded that some localized permanent deformations may occur in the structure during a major earthquake. This could misalign the drawbridge mechanism and keep it from functioning properly. Because boat traffic along the China Basin



Channel is light, it is highly unlikely that the bridge would be in the open position during an earthquake. Though the bridge may be jammed closed for an extended period of time following a major earthquake, it should still be passable to most traffic.

Up to 2 feet of soil settlement is expected to occur in the area surrounding the bridge structure due to consolidation of the underlying soil mass and lateral spreading of soil into China Basin Channel. This will result in soil settling away from the the pile supported bridge making it temporarily inaccessible to traffic.

One approach for minimizing the risk of extended loss of access to the Third Street Bridge due to soil settlement is through the use of emergency planning. By having contingency plans developed, it should be possible to rapidly mobilize heavy equipment and implement temporary repairs to the bridge approach following a major earthquake. Temporary bridge approaches can be rebuilt if the preparedness plan includes the provision of fill material (perhaps as part of an earth berm within the nearby open space areas).

For the Fourth Street Bridge, the results of the detailed seismic analysis concluded that the counterweight tower and main trunnion columns were severely overstressed. Large deflections of the counterweight were predicted raising the concern that failure of the counterweight support structure may occur, blocking bridge access. Remedial strengthening of the bridge was recommended along with rehabilitation of the reinforced concrete support structure.

Strengthening details and estimates of costs were provided as part of the study. However, the bridge was not retrofitted because of pending concerns about the

elevation of the bridge relative to the high tide level. According the San Francisco Public Works Department, long-term plans are being considered to raise the elevation of the bridge.

This bridge has a high probability of being damaged during a major earthquake. It is expected that the bridge will not be usable for an extended period following an earthquake due to failure of the counterweight support structure blocking bridge access. In addition, the concerns noted above regarding soil settlement are also applicable to this structure.



Railroad Transportation. Rail transportation systems being considered in the Mission Bay Project are (1) public transportation and (2) freight rail service. Public transportation systems include the Peninsula Commuter Rail Service (Caltrain) and the Municipal Railway Surface Rail Systems (Muni Metro Light Rail Service and the "E" Line streetcar).

Several routing schemes for the Commuter Rail Service (Caltrain) through the Mission Bay Project site have been proposed. All of the proposed routes have the tracks entering the Mission Bay site slightly east of the corner of Mariposa Street and Pennsylvania Avenue and proceeding in a north-westerly direction parallel to Seventh Street. All of these approaches place the tracks close to the 1853 shoreline and beneath I-280.

Routing schemes proposed for the Muni Metro/E Line Streetcar system are similar to that of the Caltrains with the exception that one proposed scheme has the system crossing the China Basin Channel near its southwest end.

Two basic routes are being considered for the rail freight service system. The first is again similar to the proposed Caltrains route discussed above. The other is to use the existing tracks on the Third Street bridge and route the tracks along Illinois or China Basin Streets, nearer to the Bay.

In general, the further away the tracks are placed from the Old Mission Bay shoreline, the greater the expected soil related failures during a strong earthquake. These failures include subsidence, liquefaction, and lateral spreading.

The most significant risk to the local rail system infrastructure in the vicinity of Mission Bay is due to severe damage occurring to the elevated portion of I-280 as discussed previously. Local failure of the freeway could temporarily block the tracks.

One additional consideration is the possibility that a rail station may be constructed beneath the freeway. It is recommended that a detailed seismic evaluation of the elevated freeway be conducted prior to final siting of any rail station. This will preclude the possibility that a section of the freeway will fall on top of the rail station or that strengthening of the freeway is not a cost effective option.

Port and Harbor Facilities. Two primary hazards exist to harbors and ports: earthquake-induced soils failures and tsunamis. These sites generally have loose to medium dense cohesionless soils that are in a water saturated state. During strong earthquakes, soils may temporarily liquefy resulting in foundation failures, lateral spreading, and submarine sliding of soils towards the open channel or bay.



As previously discussed in Chapter 3, this type of damage is most effectively mitigated by deep pile foundations. Pile foundations of structures located adjacent to the Bay should have special consideration given to the high lateral loads which could occur due to liquefaction or submarine sliding as soil flows towards the bay.

The Dames & Moore report (Reference 13) noted that tsunamis are not a major hazard at this site due to the protection offered by San Francisco Bay and the very low probability of such an event. Minor flooding may occur at the site due to a tsunami.

Key components of Mission Bay lifeline systems include telephone, electrical, gas and liquid fuel, water, and sewage. It is expected these systems will typically be installed as underground utilities.

Good earthquake performance of these systems is desired in order to minimize risk to people within the Mission Bay site. In particular, water systems should be designed to be as reliable as possible to minimize the risk of earthquake induced fires. Good performance of the electrical system is important in order to provide lighting as soon as possible following the earthquake. Sewage systems must remain operable to prevent post-earthquake spread of disease.

Post earthquake investigations have generally shown adequate performance of these systems in urban areas with good soil conditions. Overall system downtime following a major event would most likely be only a few hours or days. In the case of Mission Bay, complete restoration of the system could take several weeks or more. Because these systems are highly redundant, it usually is possible to temporarily reroute around a damaged section and restore function while repairs are implemented.



5.2 Lifeline Systems

General recommendations for minimizing the risk to these systems are presented below.

Electrical and Telephone Systems. Important elements of the electrical system for the Mission Bay project include distribution, power control and backup services. The site distribution system will most likely consist of underground reinforced concrete pipe manways containing electrical cables and transformer vaults.

Telecommunication systems within the Mission Bay area most likely will consist of telephone cables and switchgear. It is anticipated that most of telecommunications cables will also be located in underground conduit.

Underground distribution systems have generally performed well during earthquakes. The primary exception is when a system has crossed a fault rupture zone, passed through an area where slope failure has occurred, or has been subjected to extreme soil settlement. In these cases, cables have failed due to either an abrupt (guillotine-type) break or as a result of excessive stretching and tearing of the cable.

General recommendations to minimize damage to distribution systems include providing good anchorage for all system components such as transformers and switchgear. Where relative movement is expected between equipment, flexible connections or slack should be used to accommodate differential displacements. Slack should also be provided in underground cabling as it is installed. This will help cables accommodate potential differential settlement that is expected throughout the site and also at interfaces with pile supported buildings.





Emergency electrical generators should be provided at all important facilities such as hospitals, fire stations, and police stations to provide backup power. Preferably, generators should be located at ground level and should not be mounted on spring isolation systems unless they are specifically designed for seismic loads. Cooling and fuel supply systems for the generators should be adequately anchored to prevent premature damage during an earthquake. Starter batteries should be mounted in a battery rack that is adequately anchored to the floor or generator skid.

If batteries are used as emergency electrical systems, batteries should be stored in low profile battery racks and adequately anchored to the floor to prevent sliding and overturning. The frame of the battery racks should have sufficient strength to withstand lateral loads from the batteries. A noncorrosive padding should be placed between each battery and between the batteries and side support rails to prevent relative movement between the batteries.

Pipeline Systems. Pipelines within the Mission Bay site may consist of gas and liquid fuel, water and sewage. Damage to underground piping is expected in the Mission Bay area as well as the surrounding areas of San Francisco during a major earthquake.

One of the major post-earthquake requirements is assuring that water can be delivered throughout the Mission Bay site at sufficient pressure and flow rates for fire fighting purposes. Another is to adequately dispose of sewage and provide sufficient potable drinking water. Gas will be required to heat buildings. To achieve these goals and minimize risk, a well thought out and redundant system is required.

Pipelines are vulnerable to uneven settlement of the ground surface during an earthquake. Connections between pipe segments may open, necessitating repair. Stiff couplings such as cement or lead-caulked, bell-and-spigot couplings or bolted flange couplings perform worse than flexible couplings such as a rubber gasket. Welded steel pipe has a better performance record since it can accommodate limited amounts of differential settlement without failure. In addition, the utility interface with pile supported structures has also proven to be a problem area since utilities will move with the soil as it settles and tend to fail at their connection to the unmoving structure.

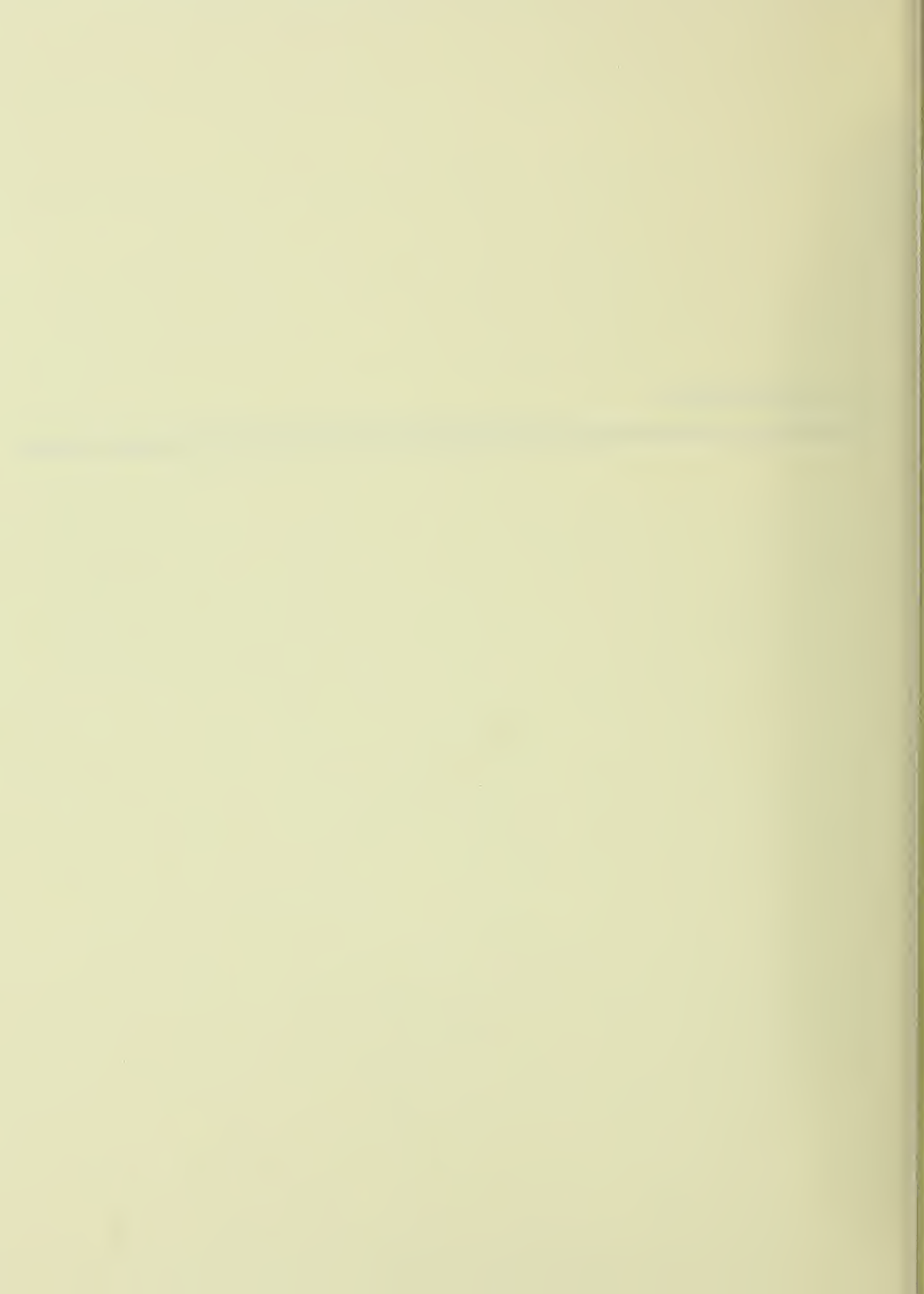
Internal and external corrosion is often a key factor in the seismic performance of underground pipes. Corrosion-related failures were observed throughout the San Fernando Valley following the 1971 earthquake.

In summary, extensive experience data on the performance of underground pipes exist. The experience points out clearly that certain types of pipe are more vulnerable to settlement damage. For example, for communications conduit, steel conduit perform better than polyvinyl chloride conduit. Ductile iron and steel pipes perform much better than cast iron or concrete pipes for potable water and waste water applications.

In order to minimize risk to this site, it is recommended that the City carefully consider the design of the underground facilities and retain consultants to ensure maximum application of current knowledge.

6. REFERENCES

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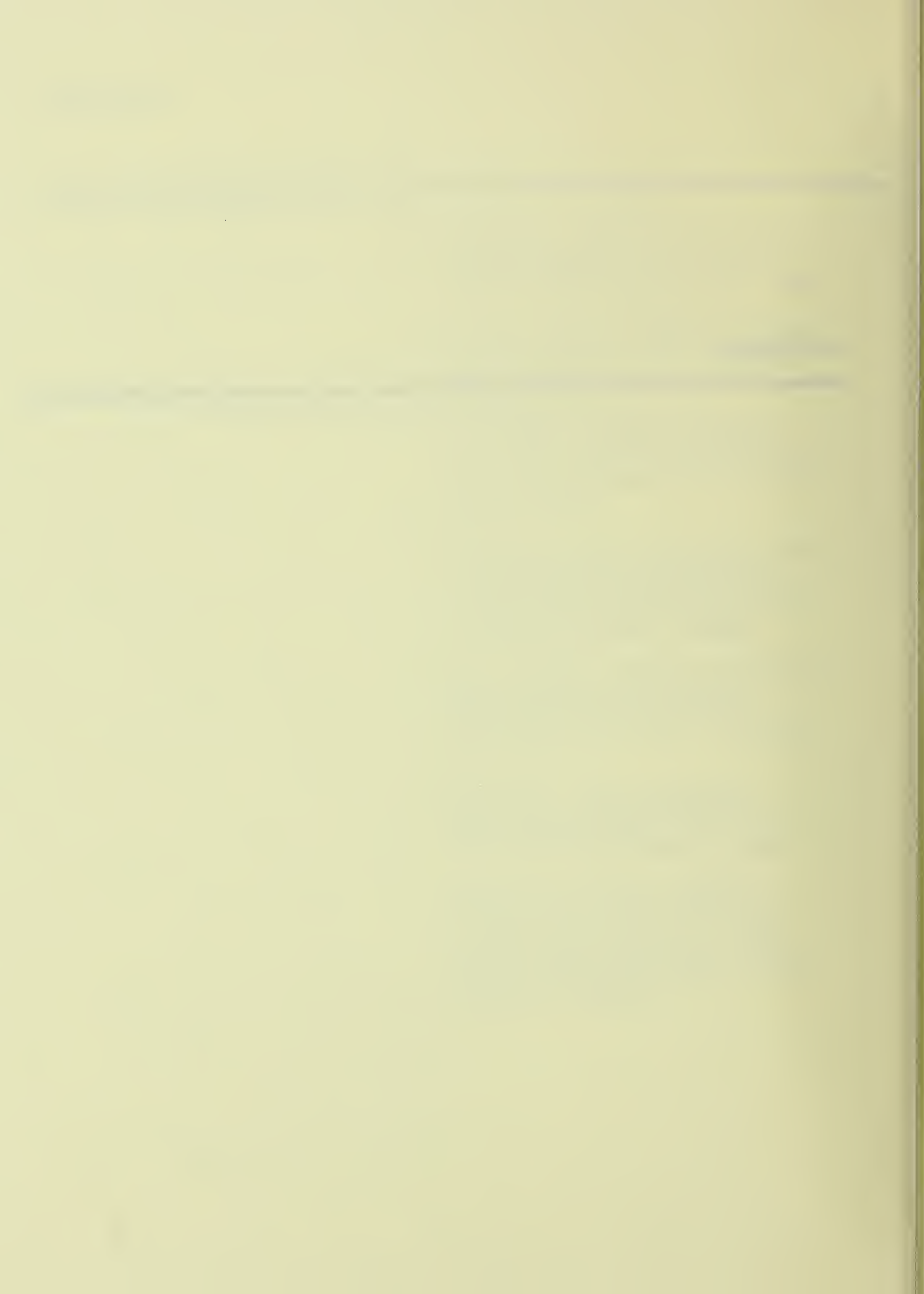


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1. City and County of San Francisco. City Planning Department. *Choices for Mission Bay, Planning Considerations: Mission Bay. San Francisco.* Draft report. June 11, 1986.
 2. Carnegie Institute. State Earthquake Investigation Commission. *The California Earthquake of April 18, 1906.* Volume I. 1908. Reprint. Washington, DC, 1969.
 3. International Conference of Building Officials. *Uniform Building Code.* Whittier, CA, 1985.
 4. City of San Francisco, Bureau of Building Inspection. *City of San Francisco Building Code,* 1979.
 5. City and County of San Francisco. City Planning Department. *Background and Preliminary Findings Report. Mission Bay. San Francisco.* Draft Working Paper. November 8, 1985.
 6. Murphy, L. *San Fernando, California. Earthquake of February 9, 1971.* Volume II: Utilities, Transportation and Sociological Aspects. Washington, DC, 1973.
 7. URS/John A. Blume and Associates, Engineers. *Seismic Safety Evaluation of Existing San Francisco Bridges.* Volume I. Prepared for the City and County of San Francisco, Department of Public Works. November 1984.
 8. American Society of Civil Engineers. *Advisory Notes on Lifeline Earthquake Emergency.* New York, NY, 1983.

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9. Kawasumi, H., Editor. *General Notes on the Nigata Earthquake of 1964*. Tokyo: Tokyo Electrical Engineering College Press, 1968.
 10. National Academy of Sciences. *The Great Alaska Earthquake of 1964: Engineering*. Washington, DC, 1973.
 11. ELS/Elbasani and Logan, Architects. *Office, Retail, and Research and Development Prototypes for Mission Bay*. Draft report. August 18, 1986.
 12. Jefferson Associates. *Mission Bay Project. Southern Pacific Development Company, Community Services and Facilities: Issues and Existing Conditions*. June 1982.
 13. Dames and Moore. *Geotechnical Consultation, Mission Bay Project, San Francisco, California*. Project Number 12756-001-03. July 9, 1982.
 14. Christopher, A. and R. Reitherman. *Building Configuration and Design*. New York: John Wiley and Sons, Inc., 1982.
 15. Yanev, P. et al., *Student Manual for Earthquake Hazard Mitigation for Utility Lifeline Systems*. Prepared for Federal Emergency Management Agency by EQE Incorporated. May 1983.

APPENDIX

11



This appendix provides background information on the seismic hazard in the San Francisco Bay Area for the interested reader. Sections A.1 and A.2 present a general discussion of the more important types of seismic hazards and is primarily intended for readers unfamiliar with earthquake terminology. Section A.3 reviews the earthquake history of the San Francisco area. A general discussion of major faults that contribute significant seismic risk to the Bay area is presented in Section A.4.

A.1 Ground Shaking

Ground shaking is the major cause of damage in most seismic events. This is due to the large area affected by a major earthquake, the consequent potential for widespread damage, and secondary effects that may occur such as ground liquefaction or settlement.

The size of the affected area depends on the magnitude of the seismic event as well as on local geological conditions. For areas underlain by deep alluvium or soft soils, ground shaking may be severely amplified (e.g., Mexico City during the 1985 Mexico earthquake), whereas a bedrock site may experience little or no amplification of motion. The intensity of ground shaking generally decreases with the distance from the epicenter of the earthquake.

The severity of an earthquake is most commonly expressed by either the Richter Magnitude or by the Modified Mercalli Intensity Scale. The Richter Magnitude (M), is a standardized measure of the amplitude of the seismic waves 100 kilometers from the earthquake's epicenter. The scale is logarithmic in design with each whole number representing an increase of 10 times in the measured earthquake wave amplitude and an

approximate increase of 32 times in the amount of energy released. For example, an earthquake that registers M8 on the Richter scale is 10,000 times as large in amplitude and would release almost one million times more energy as one measuring M4.

Correlation of structural damage to earthquake ground shaking is usually described in terms of intensity. Intensity relates directly to observed damage and depends on the distance from the fault rupture to the site and local geological conditions. The most commonly used scale is the 1931 Modified Mercalli Intensity (MMI) scale shown in Table A-1.

The MMI scale is a subjective rating with 12 discrete levels. The first five levels (MMI I through MMI V) do not involve damage to facilities or economic loss. Levels MMI VI through MMI X are characterized by increasing damage to engineered facilities, economic loss, and human casualties. Levels MMI XI and MMI XII relate primarily to ground surface effects rather than response of structures.

It is difficult to directly compare these two different methods of measuring an earthquake. The Richter Magnitude is a quantitative measure of energy released at the focus of an earthquake while intensity is a more qualitative measure of ground shaking at the location of interest. MMI readings are based on a number of factors including human perception, damage to man-made structures, landslides, etc. These factors can be significantly influenced by local geologic conditions. However, a rough correlation between the maximum intensity and magnitude of an earthquake can be made as shown by Table A-1. This table provides a currently accepted comparison between the two scales and offers the reader a general indication of the type of damage that can be expected from a given magnitude earthquake with nearby epicenter.

Table A-1
Comparison Of Earthquake Magnitude And Intensity*

Richter Magnitude (M)	MMI	Modified Mercalli Intensity Scale of 1934
2	I	Not felt except by a very few under especially favorable circumstances
	II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
3	III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
	IV	During the day felt indoors by many, outdoors by few. At night some awoke. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
4	V	Felt by nearly everyone, many awoke. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
	VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
	VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

* Magnitude (M) and intensity (MMI) comparison at epicenter (Richter, 1958)

Table A-1 (Cont.)

Comparison Of Earthquake Magnitude And Intensity*

Richter Magnitude (M)	MMI	Modified Mercalli Intensity Scale of 1934
6	VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
7	IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
	X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
8+	XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
	XII	Damage is total. Practically all works of construction are damaged or greatly destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

* Magnitude (M) and intensity (MMI) comparison at epicenter (Richter, 1958)

A.2 *Seismically Induced Ground Failures*

The principal soil failures that may result due to a major earthquake are direct ground rupture due to faulting, liquefaction, lurching and lateral spreading, settlement, and seismic landsliding. Seismically induced soil failures are site specific and depend on distance to the fault, intensity of expected ground shaking, height of the existing water table, and the type of soil.

Liquefaction. Liquefaction is a sudden loss of bearing strength that can occur when saturated, cohesionless soils are strongly and repetitively vibrated. When liquefaction occurs, loose saturated granular soils densify and increasing pore-water pressure forces water to flow upward to the ground surface where it emerges in the form of fountains and sand boils. The upward flowing water produces a temporary "quick-sand" that can result in a temporary loss of foundation support. The resulting damage can be very severe as illustrated by Figure A-1.

Several conditions allow a soil deposit to be classified as potentially liquefiable:

- Low relative density
- Low intergranular cohesion
- Fully saturated condition
- Characteristic grain size distribution
- A design earthquake of high intensity or long duration

Liquefaction typically occurs in loose sand deposits where a water table exists at depths shallower than 20 feet. Shallow ground water and loose soil are localized conditions occurring either naturally or due to man-made causes and must be determined by a site specific soils investigation.



Figure A-1: Loss of Soil Bearing Capacity Beneath Apartment Buildings Due to Soil Liquefaction

Lurching and Lateral Spreading. These are similar phenomena caused by liquefaction in some subsurface horizon. The overlying ground as far away as 100 feet moves laterally toward a free surface such as a canal bank or drainage ditch. The ground surface may be virtually flat in areas where this occurs.

Settlement. Loosely consolidated soil may be compacted when subjected to seismic shaking. Subsidence and differential settlement of buildings, highways, and other structures have been observed in many major earthquakes, including San Fernando (1971), Niigata (1964), and Alaska (1964) (References 6, 9, and 10). In most cases, settlement problems are associated with structures founded on poor foundation materials.

Subsidence may also occur due to direct tectonic displacement of the bedrock. This was well documented in the Alaska earthquake in 1964 and in San Fernando in 1971, with regional subsidence and uplift of several feet observed.

Surface Faulting. Faulting is perhaps the best known and most spectacular manifestation of earthquakes. However, it is one of the lesser hazards since earthquake fault ruptures are usually only a few feet wide and may not propagate to the ground surface. Construction directly above known fault zones must be avoided to preclude damage due to surface faulting.

Seismic Landsliding. It is generally accepted that areas with current landslide problems will experience some seismic landsliding during a major earthquake. Natural landslides and rockslides occur frequently throughout California because young and weak geologic formations are commonly aggravated by frequent faulting and alternating periods of heavy precipitation and dry weather. For example, slides continually occur on the weakly consolidated sandy bluffs along the northern California coast from Daly City to Santa Cruz. These areas are expected to experience significant problems during a major earthquake.

The severity of the damage will largely depend upon the duration and intensity of the ground shaking and whether or not the earthquake occurs during the summer or winter months. More severe damage is anticipated if a major quake occurs during the rainy season when hillsides are saturated with water and are less stable. Landslides are most common for slopes over 15 degrees

Tsunamis. Tsunamis are extremely long ocean waves that can be caused by underwater earthquakes, volcanic eruptions, or submerged landslides. The waves travel at a high velocity (400 to 600 mph) and can produce damage at great distances from the source of the disturbance.

A.3 *Earthquake History of
the San Francisco Bay Area*

The Mission Bay site is located in one of the highest earthquake risk areas in California. Several large, well-known, active faults are in the general vicinity including the San Andreas, Hayward, and Calaveras faults. These faults have caused several destructive earthquakes in the past and are potential sources of future destructive shocks. The location of the site relative to major San Francisco Bay Area faults is presented in Figure 3-2.

The recorded seismic history within 100 miles of the Bay Area begins in the year 1800. Before the 1900s, low population density and a lack of instrumentation limited the reliability of intensity ratings and epicenter locations in the area. An even more serious limitation is the possibility that smaller earthquakes may be inadequately documented or absent from the historic record because of low population density.

Numerous damaging earthquakes have occurred in the San Francisco Bay Area along the San Andreas fault. The earliest known record is of a series of earthquakes in the vicinity of San Juan Bautista during October of 1800. Another strong earthquake with an estimated magnitude of 7+ occurred on the San Francisco Peninsula in June or July of 1838. Contemporary accounts describe a long fissure reaching from San Francisco to a point near Santa Clara. Severe ground motion was felt in San Francisco, San Jose, Santa Clara, Redwood City, and as far away as Monterey.

A series of smaller earthquakes between 1850 and 1865 extensively damaged different sections of the bay area, including San Francisco, Santa Rosa, San Jose, Santa Clara, and Santa Cruz. The shock of October 8, 1865, was the most damaging of this period.

The San Francisco earthquake of April 18, 1906, is one of the world's most famous and significant earthquakes. This earthquake occurred along the northern segment of the San Andreas fault and had a magnitude of about 8.3. Very strong ground shaking was generated which was felt in all of the surrounding states; a land area of about 375,000 square miles. Approximately 270 miles of surface and submarine faulting occurred stretching along the coast from Point Delgada, south of Eureka, to Hollister. Horizontal displacements of 20 feet occurred in Marin County. The earthquake was followed by numerous aftershocks.

San Francisco suffered damage estimated variously between \$350 million and \$1 billion (1906 dollars), and several other towns, notably Santa Rosa and San Jose, suffered proportionately greater damage. Significant damage was also experienced throughout coastal northern California and extended down into central and southern California.

The Hayward Fault has also been the cause of several destructive earthquakes, including the Hayward Earthquake of 1836, one of the largest ever to occur in Northern California. According to a recent study of the event, faulting was traced from San Pablo to Mission San Jose. In another destructive shock in 1868, the fault ruptured for about 20 miles, from Warm Springs in Fremont to Mills College in Oakland. Numerous structures in San Francisco, particularly in the filled areas along the Bay, were damaged or destroyed. Both of these earthquakes were in the magnitude range of 6.8

The largest known earthquake on the Calaveras fault occurred in 1861 near Dublin. The magnitude is estimated to have been about 6.0. Damage was locally severe but little is known of the effects because of sparse population at the time. In 1898, a similar earthquake shook the Vallejo area and damaged the Mare Island Navy Yard. No surface fault rupture was found. In recent years, the Calaveras fault has been fairly active. The Morgan Hill event generated a series of magnitude 5+ earthquakes in the 1970s and 1980s, as well as the April 1984, magnitude 6.2 Morgan Hill earthquake. It was centered near Mount Hamilton, about 12 miles east of San Jose. Most of the damage and areas of high ground motion were south of the epicenter in Morgan Hill and Gilroy.

A.4 Active Faults

Strong motion from the three major faults in the Bay Area are expected to affect the Mission Bay Project area in the future. The San Andreas and associated faults on the western side of the Bay depression are collectively known as the San Andreas rift zone. The Hayward and Calaveras faults branch from the San Andreas Fault south of Hollister and, are closely related in age and movement to the San Andreas fault. Analyses of ground ruptures from historical earthquakes and ground creep (slow slippage along a fault not accompanied by an earthquake) indicate that all of these major faults are active. A brief summary of each of these faults is presented below.

San Andreas Fault. Frequent earthquakes occur on this major right lateral fault that extends from the Gulf of California in the south, northwest through the central part of California into the San Francisco Bay area. It passes within about 8-1/2 miles of Mission Bay at its closest approach.

The 1906 San Francisco earthquake which was about a magnitude 8.3 event occurred along the northern segment of this fault. Recent studies concluded events comparable to the 1906 earthquake may reoccur in northern California at average intervals of about 225 years.

Hayward Fault. The Hayward fault extends in a northwesterly direction from south of the city of San Jose to the city of San Pablo, a distance of about 55 miles. It is a right lateral fault that has been the site of many major historical earthquakes. The largest recorded events on this fault occurred in 1836 and 1868. This fault passes within about 10 miles of Mission Bay at its closest point.

Calaveras Fault Zone. The Calaveras fault zone is a north-northwest trending series of faults that joins the Hayward Fault southeast of San Jose. The Calaveras fault zone is comprised of several different faults, with a cumulative width of as much as five miles near San Jose. It has been traced southward from the vicinity of Vallejo in the north to beyond the town of Hollister in the south, where it probably eventually joins the San Andreas fault. The total length of this fault is about 120 miles. The Concord segment of the Calaveras fault zone is approximately 20 miles from the site at its nearest point.

Detailed geologic mapping of this fault zone has revealed significant right lateral creep behavior in the vicinity of Carquinez Straits. Active creep probably limits the maximum magnitude that can occur on the Concord segment of the Calaveras fault to about $M=6.0$. However, the portion of the Calaveras fault that extends south of Walnut Creek is thought to be locked and capable of an $M=7.0$ earthquake.

Other Faults. There are other active faults in the area, such as the Green Valley fault (more than 27 miles to the northeast), the Rogers Creek fault (25 miles to the north), and the San Gregorio fault (17 miles to the southwest). While these faults contribute to the overall seismic risk, they are considered to be capable of producing only moderate magnitude earthquakes.

